West Virginia Water Research Institute
Annual Technical Report
FY 2012

Introduction

West Virginia Water Research Institute

The West Virginia Water Research Institute is dedicated to the preservation and restoration of the natural environment through research and outreach with industry, government agencies, academia and the public.

Introduction

Water is one of West Virginia's most precious resources. It is essential for life and our economic prosperity, yet so many of the activities that keep our economy alive, and growing, also threaten our water resources. Energy generation, mineral extraction, agricultural production and other industrial activities all impact our water, making it increasingly necessary to find new ways to protect and restore this vital commodity as our economic activity accelerates. For over 40 years, the West Virginia Water Research Institute (WVWRI) has been leading the important work of addressing these issues and is the go-to organization for solving West Virginia's water-related problems.

While much of the work we do is focused on exploring and implementing technologies to improve and protect the quality of our State's water resources, we are also dedicated to expanding the understanding of threats and opportunities related to this critically important resource. We strive to bring together a diverse cross section of stakeholders to participate in water-related research throughout West Virginia. We encourage a constructive and respectful dialog about the future of our lakes, rivers and streams as well as our groundwater supplies.

Today, the WVWRI continues to grow its established programs and develop new initiatives to address emerging problems affecting the State's environmental and economic health. With financial support from State and Federal partners, private foundations and industry, and through the efforts of our staff and collaborating researchers, the WVWRI continues to work for real improvements to West Virginia's water resources.

Water Research for West Virginia: A Team Approach

In 1967, under Federal legislation, the United States Geological Survey established the West Virginia Water Research Institute (WVWRI) to conduct research related to water issues in the State. Today, the WVWRI develops state water research priorities with oversight and guidance from the West Virginia Advisory Committee for Water Research, a committee represented by members of Federal and State agencies, academia and industry. Our programs and projects develop strong, multi-disciplinary research teams through collaboration with West Virginia University colleges and divisions, higher education institutions across the country and industry professionals. This team approach offers the best expertise available to address West Virginia's water issues and allows the WVWRI to perform research in a number of areas at any given time. More information on WVWRI programs, research, projects, initiatives and publications can be found at www.wvwri.org.

West Virginia Advisory Committee for Water Research

Our research program is guided by the West Virginia Advisory Committee for Water Research. It includes representatives from the following:

West Virginia Department of Natural Resources West Virginia Bureau for Public Health West Virginia Coal Association West Virginia Department of Environmental Protection West Virginia Oil and Natural Gas Association GenPower Services, LLC U.S. Federal Bureau of Investigation U.S. Geological Survey U.S.

Environmental Protection Agency Region III U.S. Department of Energy - National Energy Technology Laboratory U.S. Army Corps of Engineers - Huntington, WV District West Virginia University Extension and Public Service

The Advisory Committee develops the Institute's research priority list, reviews its progress and selects startup projects at its annual meeting. With this direction, the Institute recruits new researchers to study emerging water research issues. Because the Advisory Committee understands future regulatory and economic driving factors, these issues tend to grow in importance and have often led to follow-on funding from their agencies.

Funding Strategy

The Institute received a grant of $55,525 through the U.S. Geological Survey Clean Water Act section 104b program. We use this funding along with State funding to develop research capabilities in priority areas and to provide service to State agencies, industry and citizen groups. Our strategy relies on using the USGS section 104b funding to develop competitive capabilities that, in turn, translate into successful proposals funded by a broad spectrum of Federal and State agencies.

Our strategy also relies on maintaining a broad cadre of researchers within WVU and other institutions within the state. We also work with faculty from institutions across the country to form competitive research partnerships. As West Virginia University is the State's flagship research institution, its researchers have played the dominant role. Our funding strategy relies on successful competition for Federal dollars while teaming with State agency and industry partners. The later provide test sites, in-kind support and invaluable background data. The institute has 15 full time staff. The institute also supports numerous students (6 within the WVWRI) and more through other departmental projects. All but two positions are supported entirely on grant funds. Roughly two-thirds of the Institute staff is directly engaged in research projects; the remaining is engaged in community economic redevelopment, outreach, and administration.

Research Priorities

The following is a list of state research priorities identified by the WV Advisory Committee for Water Research for 2012-2013.

Shale Gas: - energy production impacts on water resources (oil and gas drilling; hydroelectric; biofuels; etc.); - water quality/quantity concerns for gas well hydrofracturing (basin/county/state methods and estimates; need for standard for total dissolved gas); - sediment and erosion control (pads and gas lines); Coal Mining: - uses for mine water discharge (drinking water potential for underground mine pools, irrigation, industrial heating/cooling); Aquatic Ecosystem: - flooding; aquatic ecosystem integrity (anti-degradation, water quality criteria, nutrient/pathogen impacts, headwater stream valuation/mitigation); - water metrics (methods for measuring physical, chemical, biological components, in situ monitoring, PPCP's, pathogens in drinking water); - water quality (understanding consumptive uses, altered hydrology with basins, sustainability of stream gages and hydrologic data, climate variability and change, basin-wide regulatory authority of water uses, ecological flow consideration) Urban development: - industrial processes and urban sprawl (water budgets, contaminants, flooding, groundwater recharge, storm water applications); - land use modification (urban impervious surfaces and transfer of land from agriculture/non-developed to urban); - inadequate infrastructure (non-existent, failing, or aging water management infrastructure including straight pipes, septic/sewer systems, dams, levees). Agriculture: - agricultural impacts (consumption and runoff; nutrients, pesticides, herbicides).

Research Program Introduction

None.

Identifying Geomorphic Design Parameters to Improve Flood Control and Water Quality

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Civil and Environmental Engineering, WVU, PO Box 6103, Morgantown WV, 26056
WV Water Research Institute, WVU, PO Box 6064, Morgantown, WV 26506

Abstract

Fluvial geomorphic landform design has the potential to improve water quality while restoring productive stream channels in the reclaimed landscape. The technique is difficult to apply in the southern West Virginia coal fields in part due to the absence of unaltered landform data to serve as reference design values. This research examined the application of geomorphic landform design principles to valley fills. The objectives of this research were to quantify mature landform features in an undisturbed watershed in southern West Virginia and compare these characteristics to default parameters utilized in a current design tool. Reference landform characteristics were quantified in the Whetstone and Oldhouse watersheds located in the Panther Wildlife Management Area in southern West Virginia. A topographic survey was completed to quantify ridge to head of channel distance, channel slope, and hillslope profile. Channel grain size distributions were quantified in both head of channel and watershed outlet locations. Findings suggest that the slope at the head of channel ranges between 16 and 43 percent, with the slope at the mouth remaining at 8-14 percent. Drainage density was calculated as 5.3 km^{-1}, and sinuosity remained close to one (≤1.12). These design parameters substantially differ from design inputs of current design tools. The practicality to Appalachian valley fill stream construction is that the stream lengths are shorter and the land slopes are steeper with straighter head water channels compared with other areas of the United States. While the application of geomorphic landform design to surface mine sites presents challenges, this work provides support for the future application.

Table of Contents

List of Figures

List of Tables

Executive Summary

This project examined the application of geomorphic landform design principles to valley fills. The work was intended to help determine if geomorphic landform design is a viable reclamation option for Central Appalachia. Geomorphic data were collected to quantify undisturbed landforms. These data were used to calibrate a conceptual geomorphic landform design of a valley fill in southern West Virginia.

Introduction

Approximately 2,000 km of headwater streams were lost by 2002 due to surfacing mining disturbance in the central Appalachian region (USEPA 2011). Typically, the horizontally bedded seams are removed sequentially as overburden is placed both on the pit floor and in external valley fill dumps. Conventional valley fills under West Virginia regulations are designed to meet minimum design requirements to achieve geotechnical stability and to control surface runoff. State regulations (WVDEP 1993) require:

i. A long-term static factor of safety of 1.5;
ii. 2:1 slopes with minimum 20-ft wide benches installed within every 50 vertical feet;
iii. Internal drainage provided by a vertical rock chimney (minimum width of 16 ft); and,
iv. Surface drainage for a 100-yr, 24-hr precipitation event.

The resulting surfaces often have planar slope profiles which contrast with the surrounding landscape, and their increasing size has resulted in an increasing loss of headwater streams. Studies have shown that streams below valley fills often have elevated dissolved ion concentrations resulting from water contact with the overburden (Hartman et al. 2005; Pond et al. 2008; Petty et al. 2010). Additionally, research has documented that surface mining and reclamation increase stormflow response compared to the undisturbed condition (Bonta et al. 1997; Messinger 2003; Messinger and Paybins 2003; Negley and Eshleman 2006), and selenium leaching from spoil related to coal mining is of increasing concern (e.g. Ziemkiewicz et al. 2011).

Fluvial geomorphic landform design has the potential to improve water quality while restoring productive stream channels in the reclaimed landscape. Under natural conditions, landforms develop a balance between erosive and resistance forces, resulting in a system in dynamic equilibrium with low erosion rates. The fluvial geomorphic landform design approach attempts to design landforms in this steady-state condition, considering long-term climatic conditions, soil types, slopes, and vegetation types (Toy and Chuse 2005; Bugosh 2009). Relative to traditional reclaimed landforms, fluvial geomorphic landform design appears natural, reduces long-term maintenance, requires fewer artificial elements, and supports long-term stability (Martin-Duque et al. 2009).

This design approach has been used with success (e.g. Toy and Chuse 2005; Measles and Bugosh 2007; Martin-Moreno et al. 2008; Bugosh 2009; Robson et al. 2009; Marin-Duque et al. 2009) but has not been utilized in Appalachian surface mining reclamation. The complexity of mature landform design in steep terrain presents challenges. In addition, current regulations do not support the utilization of the design technique (Michael et al. 2010).

Geomorphic landform design uses a reference landform approach which requires pre-development geomorphic data. The data needed for design are similar to those needed for stream classification systems (e.g. Schumm and Mosley1977; Rosgen 1994, 1996; Montgomery and Buffington 1997) and stream assessments (e.g. Kaufmann and Robison 1998; VANR 2004):

i. main channel slope;
ii. drainage density;
iii. longitudinal profile shape;
iv. channel characteristics (bankfull width, width to depth ratio, sinuosity, meander belt width, "A" channel length); and,
v. ridge to head of channel distance.

Limited geomorphic data are available in West Virginia, especially in the southern coal fields (e.g. Wiley et al. 2001). This region has a history of surface mining and logging, often requiring changes of the steep terrain for site access, which has rendered limited unaltered land profiles.

The overall goal of this research was to quantify geomorphic features in an undisturbed watershed in southern West Virginia. The data were used to inform geomorphic landform design for valley fills in Central Appalachia. Specifically, this research quantified geomorphic characteristics in Whetstone and Oldhouse watersheds located in the Panther Wildlife Management Area (WMA). These characteristics were then compared to design inputs used in a recent alternative valley fill design developed by Sears (2012). Lastly, the conceptual valley-fill design was calibrated using the measured regional design characteristics.

Experimental Methods

Study Area and Site characteristics

Two watersheds were chosen as the study areas for this project: Whetstone Branch and Oldhouse Branch. Both watersheds are located in the Panther Wildlife Management Area in McDowell County, near the southern border of West Virginia (Figure 1). The study locations were identified using aerial photography, topographic maps, and communication with area officials. The Panther WMA site is managed by the West Virginia Division of Natural Resources and has had only minor terrain impacts, mostly due to road construction. The study area receives an average of 100-122 cm of precipitation annually with a strong seasonal pattern (NRCS-NWCC 2012).

Whetstone Branch watershed (0.75 km^2) and Oldhouse Branch watershed (0.64 km^2) are characterized by a mixed mesophytic forest. Invasive species are also common to the area, including *Elaeagnus umbellate* (autumn olive), *Ailanthus altissima* (tree of heaven), *Pueraria lobata* (kudzu), and *Rosa multiflora* (multiflora rose). The Whetstone Branch watershed consists mainly of an extremely steep and stony soil (Pineville-Berks), with a small portion fine sandy loam (Yeager) located around the mouth of the stream.

The Whetstone Branch watershed includes nine major unnamed tributaries. Seven of these tributaries were selected for study based on accessibility. Field data collection was completed June-July 2012. Geomorphic characteristics were quantified at the seven head of channel locations (I, II, III, IV, V, VI, and VII) as well as the watershed outlet (M for main channel outlet; Figures 2-3). The characteristics were determined through a combination of field surveys and existing GIS data as described in the following sections. Five tributaries were studied in Oldhouse Branch watershed (I, II, III, IV, and V) as well as the watershed outlet (M); Figures 4-5).

Figure 1. Location of experimental watershed, Whetstone Branch, in Panther Wildlife Management Area, West Virginia

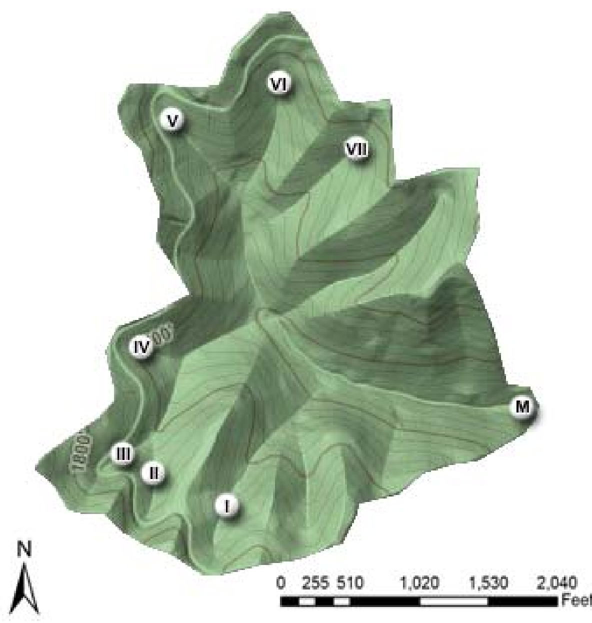

Figure 2. Head of channels surveyed in Whetstone Branch watershed

Figure 3. Experimental field sites for the head of channel sampling stations (I, II, III, IV, V, VI, VII) and the watershed outlet (M) Whetstone Branch watershed

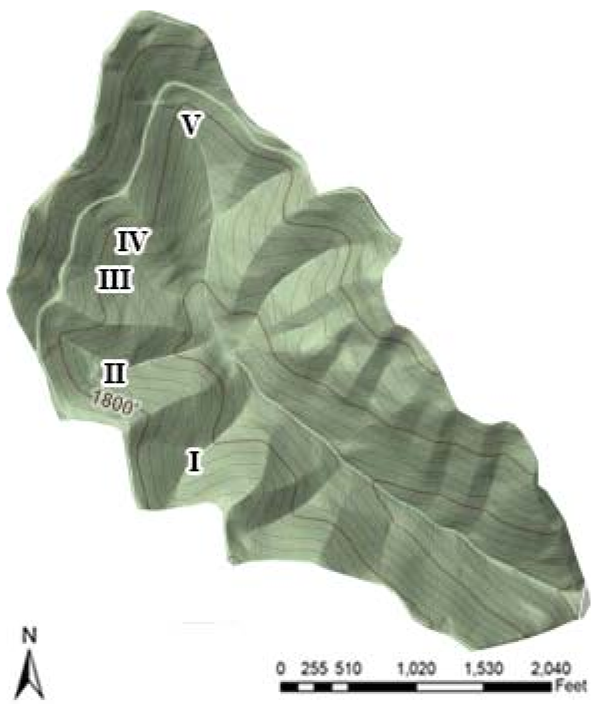

Figure 4. Head of channels surveyed in Oldhouse watershed

Figure 5. Experimental field sites for the head of channel locations in the Oldhouse watershed (I, II, III, IV, V) and outlet (M)

Data Collection and Analysis

Field data needed to quantify grain size distribution, hillslopes, ridge to head of channel distance, channel slope, and cross-sectional geometry were collected in head of channel and watershed outlet locations (Figure 2). A field survey was completed using a Topcon FC-100 and Hyperlite+ receivers (Topcon, Paramus, New Jersey) using a 0.6 m horizontal error and a 1.5 m vertical accuracy; this error represented the minimum allowable error to complete measurements within the dense vegetation cover. Study reaches were surveyed to quantify slopes, sinuosity, ridges, and channel head locations. The location of the watershed ridge and head of channel locations were identified and recorded as points; these data were used to calculate ridge to head of channel distance. Roads that altered the natural topography were also recorded. A minimum of five points were taken downslope from the start of channel to identify the channel slope and sinuosity (i.e. channel length/valley length). Bank slopes were determined through points taken a minimum of 7.5 m from the start of channel on either side of the channel. A clinometer was used to verify slope measurements. Channel dimensions were measured at the head of each channel as well as the mouth of the watershed. These sections were taken by placing an adjustable measuring rod horizontally and perpendicular to the stream; the distance from the rod to the streambed were measured and recorded at 0.3 m intervals.

Particle size distributions of bed material were quantified at each sampling locations using modified Wolman (1954) pebble count (Harrelson et al. 1994). Bank materials were also observed and recorded. Riparian trees, shrubs, and herbaceous plants were characterized at each head of channel location through sketching sections, highlighting plant types and observations of plant cover. Additionally, a percentage of each type of cover (trees, shrubs, low lying plants) was estimated based on observation.

ArcMap was used in conjunction with digital spatial datasets for elevation (U.S. Geological Survey, WV SAMB), hydrology (U.S. Geological Survey, WV SAMB), and soils (NRCS). The field measurements were downloaded into a GIS desktop application and georeferenced with the field data. GIS was used to verify slope and sinuosity measurements. Slope and aspect maps were created and drainage density (i.e. valley length/watershed area) was calculated. Ridge to head of channel distances were calculated using survey data.

Geomorphic Valley-fill Design Calibration

The regional data were used to improve a previously created valley-fill design. Three iterations were completed. The redesigned watersheds (designated as “RHC 150”, “RHC 150-R”, and “RHC 220”) were compared to the default design as well as to the regional design data.

Results and Discussion

Stream Pattern and Profile

Sinuosity, a measure of channel curvature, was calculated as nearly one when using both survey data (average sinuosity = 1.02) and GIS data (average sinuosity = 1.05) (Table 1). Channels with a sinuosity greater than 1.3 are considered meandering (FISRWG 1998); therefore, no meandering channels were observed in the steep, headwater watersheds. The sinuosity measurements calculated with field measurements were slightly smaller than those derived from GIS. This is expected because the survey only accounted for a small stretch at the beginning of the stream (where slopes are greater) while the GIS measurements represented the entire branch.

The ridge to head of channel distance represents the distance required to form channelized flow and is essential to understand watershed runoff processes (Hancock and Evans 2006). The head of channel was determined by identifying the location where soil began to give way to gravel and there was an apparent change in slope. An apparent v-notch began to form at the head of each channel as well. The mean ridge to head-of-channel distance was 121 m and 178 m for Whetstone and Oldhouse watersheds, respectively (Table 1).

For the headwater tributary locations, channel slope was greater than 16%. At the watershed outlet, the main channel had a slope of 8-14%, which is characteristic of a non-meandering stream.

Table 1. Ridge to head of channel distance, sinuosity, and channel slope for each field site

Watershed	Site	Ridge to channel head distance (m)	Sinuosity (from survey)	Sinuosity (from GIS)	Channel Slope (%)
W	I	112	1.05	1.08	16
W	II	113	1.01	1.12	18
W	III	163	1.00	1.05	21
W	IV	108	1.00	1.02	27
W	V	106	1.00	1.00	42
W	VI	136	1.01	1.06	34
W	VII	110	1.01	1.02	36
W	M	NA‡	1.01	1.03	8
O	I	104	1.02	1.02	35
O	II	171	1.00	1.07	32
O	III	220	1.06	1.09	43
O	IV	218	1.04	1.06	41
O	V	177	1.01	1.05	39
O	M	NA‡	1.01	1.04	14

‡NA=not applicable

Channel Material and Hillslope

Median particle size (D50) ranged from 18 to 43 mm for all headwater locations (W I-VII, W I-V; Table 2), representing gravel bed channels. The median particle size for the watershed outlet was also in the gravel size range (D50=20 and 45 mm). The head of channel bed material was colluvial according to the Montgomery-Buffington classification (Montgomery and Buffington 1993); it originated from hillslope debris and was formed by gravity.

Table 2. Grain size distributions for each field site

Watershed	Site	D16 (mm)	D50 (mm)	D84 (mm)
W	I	9.1	31	72
W	II	9.4	21	59
W	III	11	33	66
W	IV	9.4	22	62
W	V	8.7	19	51
W	VI	8.3	27	76
W	VII	8.4	34	63
W	M	10	20	32
O	I	9.6	43	79
O	II	9.3	30	61
O	III	8.6	26	64
O	IV	6.4	18	54
O	V	7.6	20	54
O	M	11	45	120

Banks primarily consisted of sand and tended to have slopes from 9%-25%. The heads of the channels tended to start out broad (1.8-3 m) and narrowed as they traveled down the slope

(Table 3). Channel slopes were also very steep, reaching as high as 43% grade (Table 1). The steep valley slopes are also presented in Figures 7 and 8. Much of the watershed has greater than a 50% incline, with very few areas less than 30% (Figures 7-8). The complexity of the watershed arrangement is apparent through the aspect distribution; the Whestone Branch watershed had 40%, 30%, 20%, and 10% of south (south, southwest, southeast), north (north, northwest, northeast), east, and west facing slopes, respectively (Figure 9); Oldhouse Branch had a similar distribution (Figure 10).

Table 3. Channel width, bank material, and bank slope for each field site

			Left Bank		Right Bank	
	Site	**Channel Width**	**Slope**	**Texture**	**Slope**	**Texture**
W	I	SC	VS	Sand/Silt	VS	Sand/Silt
W	II	B	S	Sand	S	Sand
W	III	B	S	Sand	S	Sand
W	IV	B	H	Sand	H	Sand
W	V	B	VS	Sand	VS	Sand
W	VI	B	H	Sand	VS	Sand
W	VII	N	S	Sand	S	Sand
W	M	B	ES	Sand	S	Sand
O	I	VB	H	Sand	H	Sand
O	II	B	S	Sand	S	Sand
O	III	VB	H	Sand	H	Sand
O	IV	B	S	Sand	S	Sand
O	V	N	S	Sand	S	Sand
O	M	B	ES	Sand	ES	Sand

*SC is semi-confined (0.6-1.2 m), B is broad (1.8-3 m), N is Narrow (1.2-1.8 m), VS is very steep (16%-25%), S is steep (9%-15%), H is hilly (4-8%), and ES is extremely steep (>25%); notation adapted from (VANR, 2004).

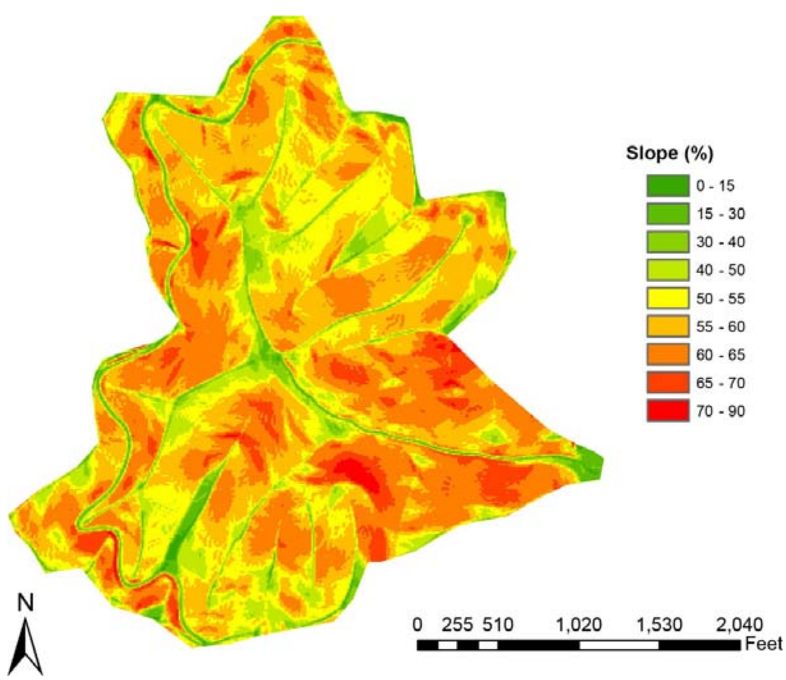

Figure 6. Slope map of Whetstone Branch

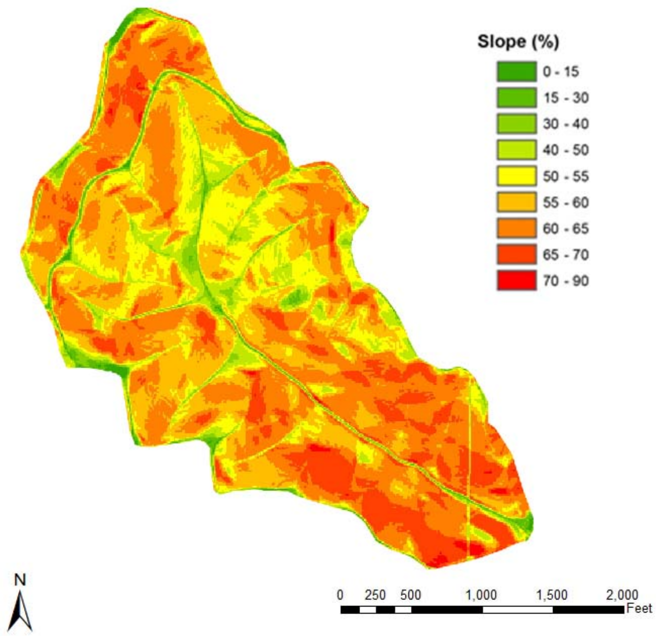

Figure 7. Slope map of Oldhouse Branch

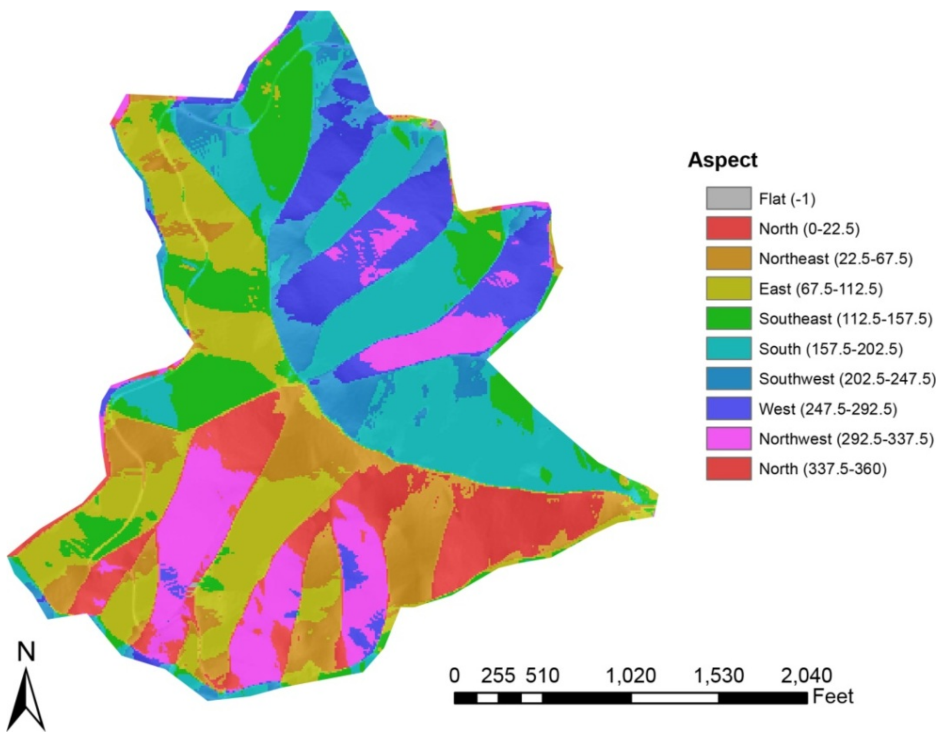

Figure 8. Aspect map of Whetstone Branch

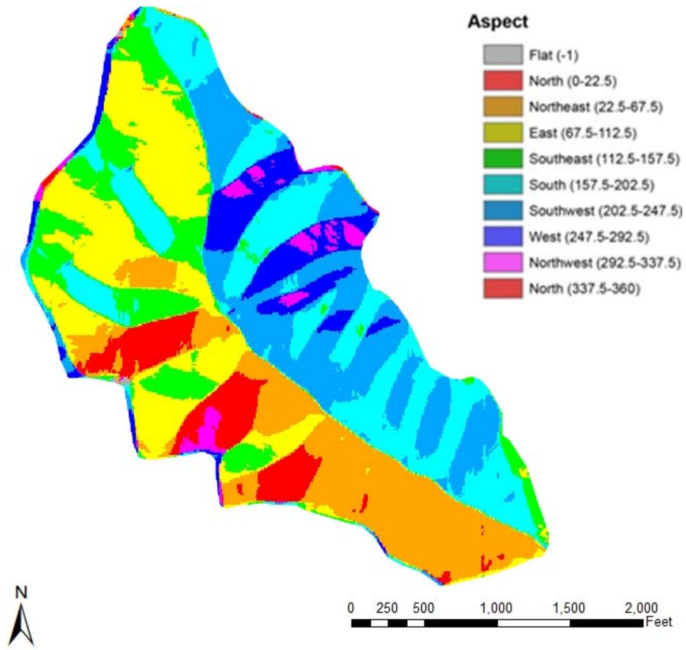

Figure 9. Aspect map of Oldhouse Branch

Comparison and Analysis of Design Parameters

Sears (2012) recently designed an alternative valley fill for a site under construction in southern West Virginia. The design applied the geomorphic landform technique and used the design tool Carlson Natural Regrade with GeoFluv^{TM}. Default design parameters that were not specific to West Virginia were utilized in the design process (Table 4).

The measured values quantified in this research varied significantly from the default settings. All observed channels were characterized as colluvial as described by the Montgomery and Buffington (1993) classification system. All channel slopes were greater than 4% for this study and all measured sinuosity values were near one. The measured ridge to head of channel distances were at least four times greater than the value utilized in the Sears (2012) design. The default drainage area was less than the measured value; however Sears (2012) allowed a 20% error (6-9 km^{-1}). The experimental watershed value (5.0-5.3 km^{-1}) fell outside of this range (Table 4).

Table 4. Comparison of default design parameters to measurements taken from experimental watersheds

	Default**	**Whetstone**	**Oldhouse**
Max ridge to head of channel distance, m (ft)	24 (80)	163 (534)	220 (723)
Slope at mouth of main valley channel (%)	2	8	14
Drainage density, km^{-1} (ft/ac)	7.5 (100)	5.3 (70)	5.0 (67)
Upstream slope (%)	12	28*	34*
Downstream slope (%)	2	8*	14*
Sinuosity (> -4%)	1.15	1.03*	1.06*
Sinuosity (< -4%)	1.48	NA‡	NA‡

*represents an average value

**default values incorporated in the design software

‡NA=not applicable

Geomorphic Valley-fill Design Comparison

The regional data were used to improve the previously created valley-fill design (designated as "Default Design"). First, the ridge to head-of-channel distance (RHC) was increased to 150 m and the drainage density (DD) was decreased to 5.3 km^{-1}, allowing a 20% variance for DD. In the second design, the stream channels were reconfigured to obtain the targeted DD while the design parameters of the first iteration remained unchanged. In the final design, the RHC was increased to 220 m (720 ft) while the DD remained at 5.3±20% km^{-1} (Table 5).

Table 5. Design parameters for subwatershed 1

	Default	**RHC 150**	**RHC 150-R**	**RHC 220**
Ridge to head-of-channel distance, m (ft)	24 (80)	150 (500)	150 (500)	220 (720)
Drainage density*, km^{-1} (ft/ac)	7.5 (100)	5.3 (70)	5.3 (70)	5.3 (70)
Channel reconfiguration	NA‡	No	Yes	No

*±20%

‡NA=not applicable

Default Design

The default design utilized criteria assigned by the software and included six subwatersheds. The DD for the channels within the entire boundary was within 0.32% - 18.9% the default design criteria, respectively, and the RHC distance was less than 24 m (mean = 10.1 m, range = 2.1 - 16.8 m). The main subwatershed (area = 0 .98 km^2) represented 70% of the area within the permit boundary. This subwatershed had the largest channel network with 13 channels, totaling 6.7 km in length. The channels were arranged in a dendritic pattern (1st-3rd order; Strahler, 1957). The 12 tributaries were classified as Aa+ channels (Rosgen, 1994) due to the steep slopes (>4%) and low sinuosity (1.13-1.16). A portion of the main channel near the watershed outlet was classified as a Rosgen type C channel, a meandering channel with reduced slopes (< 2%). The area of the remaining five subwatersheds ranged from 0.016 to 0.146 km^2 (4 to 36 ac) and had 1-2 channels also classified as Rosgen type Aa+ and C. The default design accounted for 58x10^6 m^3 of overburden which was balanced with the volume of cut material to create a comprehensive design. (See Sears (2012) for a description of the default design).

The design in the default form needed to be improved for erosion stability. Based on the regional RHC data (Table 5), all of the subwatersheds except for the main subwatershed would have only sheet flow due to the small watershed areas. The main subwatershed (Figure 10 a) was re-designed to consider the regional design parameters. The following sections describe the three design iterations.

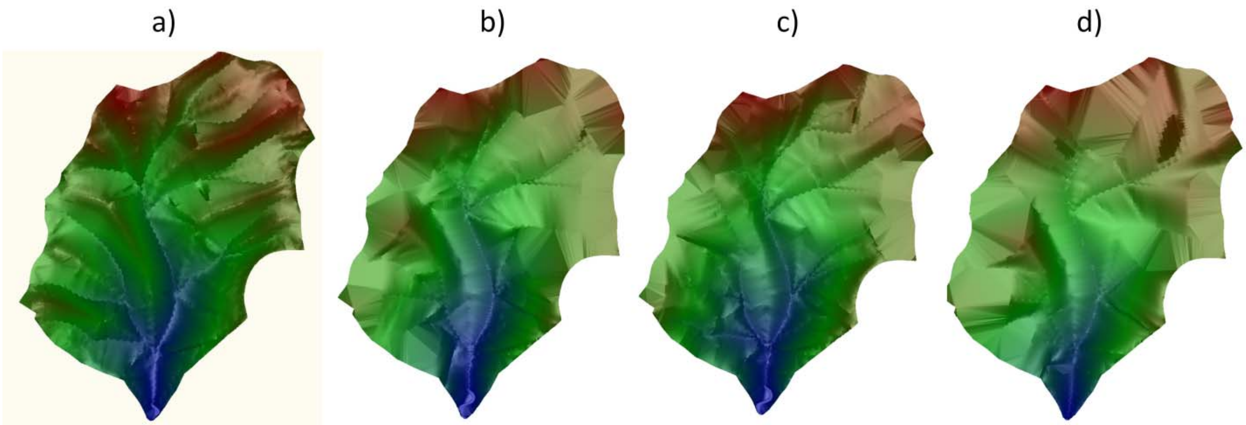

Figure 10. Comparison of four design iterations: a) default design; b) RHC 150; c) RHC 150-R; and, d) RHC 220

<u>RHC 150</u>

All of the channels that were in the default GLD were truncated at a distance of 150 m from the subwatershed boundary (Table 5). The channel pattern remained constant as compared to the default design; therefore, multiple channels in the default design were shortened or eliminated (Figures 10b, 12-13). The RHC 150 design had eight tributaries on the main channel, while the default design had 12. The DD exceeded suitable range for six of the eight tributaries (31.5%-81.7%) (Figure 11). This result suggests that altering the stream length alone was not sufficient to develop a design meeting regional criteria. Because the DD is less than desired in some locations and greater in others, in practice both erosion and aggradation would be expected to occur until equilibrium is reached.

<u>RHC 150-Reconfiguration</u>

The design criteria of the first iteration remained unchanged (DD=5.3±20% km^{-1}; max RHC =150 m) for the RHC 150-Reconfiguration design (Table 5, Figure 10 c). Stream channel pattern of the RHC 150 design was altered to obtain the target drainage density. This design had 12 tributaries and a main channel, similar to the default design; however, the design met regional design criteria. The RHC distance less than 150 m (mean=85.6 m, range=40.2-130.8 m) and the DD was within the acceptable design range (4.2-5.9 km^{-1}); six of the thirteen created channels were within 5% of 5.3 km^{-1} (Figure 11). The valley length was up to 45% less than in the default GLD due to the increased RCH length (Figure 12). The watershed area between the two designs varied up to 10% (Figure 13). Like the default design, the channels were primarily Rosgen type Aa+. Since the design used drainage concepts which emulated natural processes, it is expected to be in dynamic equilibrium in terms of erosion by creating the proper drainage density.

RHC 220

In the final design, the RHC was increased to 220 m, reducing the number of stream channels to seven tributaries and a main channel (Figs. 10d, 12, 13). The target drainage density remained at 5.3±20% km^{-1}, but DD criteria were not achieved, even with altering the channel pattern. For all channels, DD was less than the optimal range, up to 74% for one channel, suggesting that erosion would occur until the drainage areas reached equilibrium (Fig. 11).

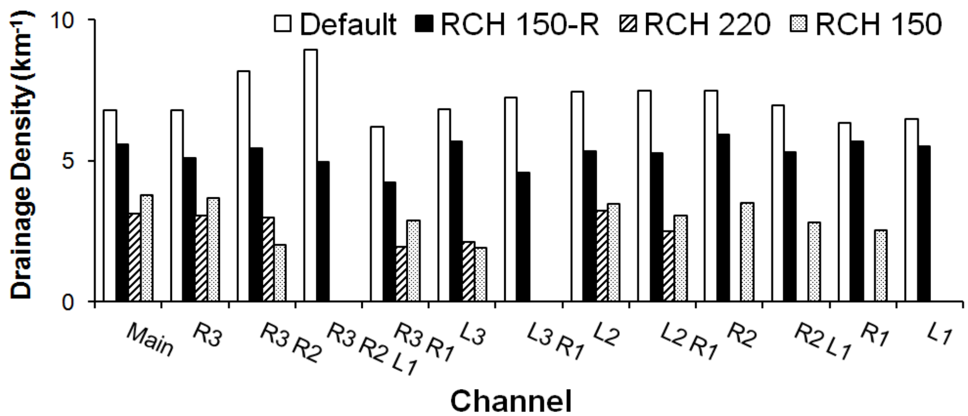

Figure 11. Drainage density for channels included in the four geomorphic landform designs; channels are named from the headwater location of the main channel moving downstream: R is right, L is left. Main considers the entire subwatershed.

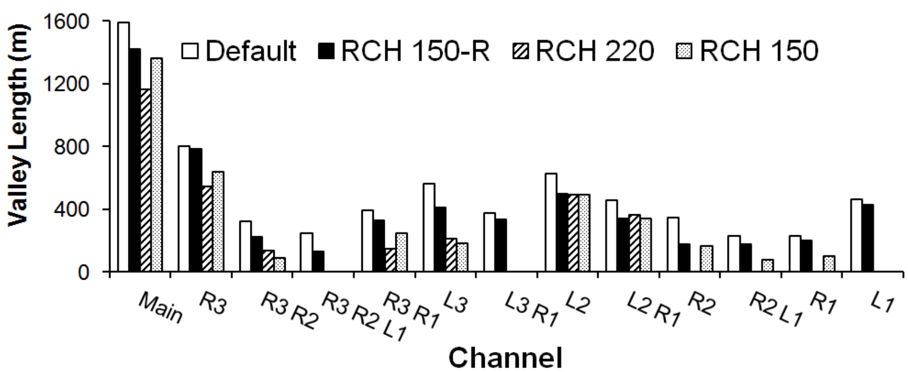

Figure 12. Valley length for channels included in the four geomorphic landform designs; channels are named from the headwater location of the main channel moving downstream: R is right, L is left. Main considers the entire subwatershed.

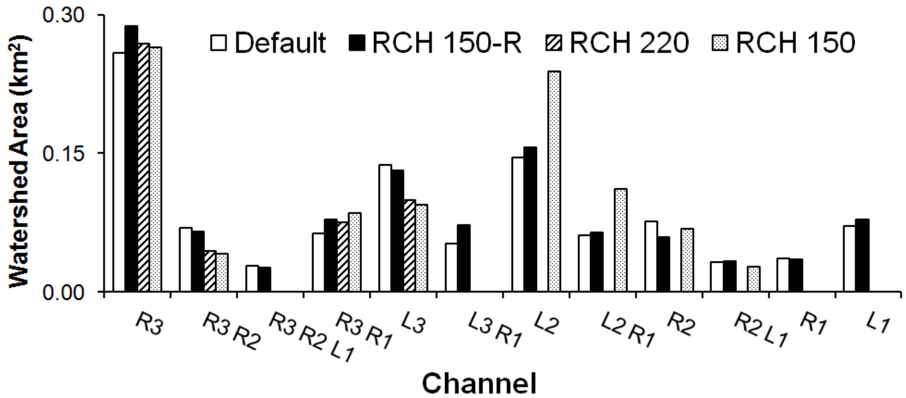

Figure 13. Watershed area for channels included in the four geomorphic landform designs; channels are named from the headwater location of the main channel moving downstream: R is right, L is left

Conclusions

These reference landform design values are critical to design a system with low erosion rates. Systems designed with a lower than optimum drainage density will likely promote sediment deposition, and systems designed with a greater than optimum drainage density will likely promote erosion, leading to instability. Difference between default and measured parameters noted in this study were somewhat expected. The default design parameters incorporated into the design software were based on semi-arid regions. The geomorphic characteristics in southern West Virginia are a result of the steep slopes, consolidated soil, vegetation, and climatic influences of the region. These characteristics need to be considered for future designs.

Because the geomorphic landform approach utilizes a reference landform design method, region specific design parameters are crucial to inform design. This research quantified the complex, steep terrain in southern West Virginia. Results from this study suggest that incorporation of GLD principles into surface mining reclamation is feasible and practical for Central Appalachia. This works illustrates the importance of field determination of the RHC input parameter. Published values previously used in design were consistently one order of magnitude less than values measured in this study, Default = 24 m versus Field = 220 m. Similarly for the DD parameter, the published range is 7.5 km^{-1} with ±20% error; 6.0 to 9.0 km^{-1}, respectively. The field measurements for Central Appalachia quantified the DD to range from 5.0 to 5.3 km^{-1}. The geomorphic characteristics in southern West Virginia are a result of the steep slopes, consolidated soil, vegetation, and climatic influences of the region. The practicality to Appalachian valley fill stream construction is that the stream lengths are shorter and the land slopes are steeper with straighter head water channels compared with other areas of the United States. These reference landform design values are critical to design a system with low erosion rates. Systems designed with a lower than optimum drainage density will likely promote sediment deposition, and systems designed with a greater than optimum drainage density will likely promote erosion, leading to instability.

Future work will quantify geomorphic characteristics in additional watersheds in the mining region of southern West Virginia. In addition, surveys of reclaimed sites of varying ages will also provide insight into generating successful designs. Designs will then be created using region specific design values and the differences in each design will be quantified. Ultimately, the research will provide the coal industry and regulators with data to advance watershed reclamation in Central Appalachia.

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Appendix A: Geomorphic Data

Table 6. Geomorphic data for Whetstone Branch watershed

Site	Whetstone 1	Whetstone 2	Whetstone 3	Whetstone 4	Whetstone 5	Whetstone 6	Whetstone 7	Whetstone Mouth
#	I	II	III	IV	V	VI	VII	M
Lat	37˚ 24' 54.9"	37˚ 24' 56.0"	37˚ 24' 59.3"	37˚ 25' 6.9"	37˚ 25' 23.5"	37˚ 25' 27.0"	37˚ 25' 21.2"	37˚ 25' 2.4"
Long	81˚ 53' 15.7"	81˚ 53' 21.0"	81˚ 53' 24.1"	81˚ 53' 22.8"	81˚ 53' 19.8"	81˚ 53' 9.7"	81˚ 53' 2.8"	81˚ 52' 45.1"
Slope	16%	18%	21%	27%	42%	34%	36%	8%
Channel Width	Semi-Confined (2-4 ft)	Broad (6-10 ft)	Broad (6-10 ft)	Broad (6-10 ft)	Broad (6-10 ft)	Broad (6-10 ft)	Narrow (4-6 ft)	Broad (6-10 ft)
Left Bank Slope	Very Steep (16-25%)	Steep (9-15%)	Steep (9-15%)	Hilly (4-8%)	Very Steep (16-25%)	Hilly (4-8%)	Steep (9-15%)	Extremely Steep (>25%)
Texture of Exposed Left Bank	Sand/Silt	Sand	Sand	Sand	Sand	Sand	Sand	Sand
Right Bank Slope	Very Steep (16-25%)	Steep (9-15%)	Steep (9-15%)	Hilly (4-8%)	Very Steep (16-25%)	Very Steep (16-25%)	Steep (9-15%)	Steep (9-15%)
Texture of Exposed Right Bank	Sand/Silt	Sand	Sand	Sand	Sand	Sand	Sand	Sand
Ridge-Head Dist on Map (m)	106.4	107.8	152.6	74.9	101.1	124.2	102.3	N/A
Elevation Change (m)	33.8	32.9	56.7	25.9	31.4	55.4	40.2	N/A
Adjusted Ridge-Head Distance (m)	111.6	112.7	162.8	79.3	105.9	136.0	109.9	N/A
Sinuosity (Field)	1.050	1.005	1.004	1.002	1.003	1.010	1.007	N/A
Sinuosity (GIS)	1.075	1.122	1.054	1.022	1.002	1.060	1.016	N/A
D16 (mm)	9.1	9.4	11	9.4	8.7	8.3	8.4	19
D50 (mm)	31	21	33	22	19	27	34	38
D84 (mm)	72	59	66	62	51	76	63	81

Table 7. Geomorphic data for Oldhouse Branch watershed

Site	Oldhouse 1	Oldhouse 2	Oldhouse 3	Oldhouse 4	Oldhouse 5	Oldhouse Mouth
#	I	II	III	IV	V	M
Lat	37˚ 25' 32.6"	37˚ 25' 34.0"	37˚ 25' 43.9"	37˚ 25' 28.7"	37˚ 25' 21.7"	37˚ 25' 13.3"
Long	81˚ 53' 00.2"	81˚ 52' 59.7"	81˚ 52' 55.6"	81˚ 53' 02.9"	81˚ 52' 55.7"	81˚ 52' 25.2"
Slope	35%	32%	43%	41%	39%	14%
Channel Width	Very Broad (>10 ft)	Broad (6-10 ft)	Very Broad (>10 ft)	Broad (6-10 ft)	Narrow (4-6 ft)	Broad (6-10 ft)
Left Bank Slope	Hilly (4-8%)	Steep (9-15%)	Hilly (4-8%)	Steep (9-15%)	Steep (9-15%)	Extremely Steep (>25%)
Texture of Exposed Left Bank	Sand	Sand	Sand	Sand	Sand	Sand
Right Bank Slope	Hilly (4-8%)	Steep (9-15%)	Hilly (4-8%)	Steep (9-15%)	Steep (9-15%)	Extremely Steep (>25%)
Texture of Exposed Right Bank	Sand	Sand	Sand	Sand	Sand	Sand
Ridge-Head Dist on Map (m)	96.5	155.6	204.2	199.9	161.2	N/A
Elevation Change (m)	38.4	70.7	82.6	87.8	72.4	N/A
Adjusted Ridge-Head Distance (m)	103.9	170.9	220.3	218.3	176.7	N/A
Sinuosity (Field)	1.019	1.002	1.057	1.041	1.012	N/A
Sinuosity (GIS)	1.019	1.071	1.086	1.064	1.045	N/A
D16 (mm)	9.6	9.3	8.6	6.4	7.6	11
D50 (mm)	43	30	26	18	20	45
D84 (mm)	79	61	64	54	54	120

1. Publications:

Buckley, C., L. Hopkinson, J. Quaranta, B. Mack, and P. Ziemkiewicz. 2013. Investigating design parameters in the design of West Virginia valley fills to support application of geomorphic landform design principles. In *Environmental Considerations in Energy Production*, (book chapter submitted for review 10/2012; reviews submitted 01/2012; expected publication 04/2013.)

2. Information Transfer Program:

- A text description of the project was added to the WV Water Research Institute (WVWRI) website (http://wvwri.org/project-listing/).

- Preliminary results were presented at the West Virginia Water Research conference as a poster (abstract published in program).

Buckley, C., L.C. Hopkinson, B. Mack, and J.D. Quaranta. 2012. Quantifying mature landform characteristics for geomorphic design in the coal-mining region of southern West Virginia. West Virginia Water Research Conference, October 30-31. Waterfront Place Hotel: Morgantown, WV. *Poster.*

- Abstract submitted and accepted to present an oral presentation at the Environmental Considerations in Energy Production Symposium:

Buckley, C., L. Hopkinson, J. Quaranta, B. Mack, and P. Ziemkiewicz. 2013. Investigating design parameters in the design of West Virginia valley fills to support application of geomorphic landform design principles. In *Environmental Considerations in Energy Production*, April 14-18, 2013.

3. Student Support:

Category	Number of students supported with 104b base grant	$ Value of students supported with 104b base grant	Number of students supported with matching funds	$ Value of student support with matching funds	Total number of students supported	Total $ value of student support
Undergraduate	1				1	
Masters	1				1	
Ph.D.						
Post-Doc						
Total	2				2	

4. Notable Achievements and Awards: Provide a brief description of any especially notable achievements and awards resulting from work supported with section 104b and required matching funds and by supplemental grants during the reporting period.

- One book chapter was submitted for review with a graduate student as the lead author. A manuscript is in preparation to submit to a refereed journal.

Development of a Drinking Water Well Sampling Protocol to Establish Baseline Data Prior to Horizontal Drilling of Gas Wells

Basic Information

Title:	Development of a Drinking Water Well Sampling Protocol to Establish Baseline Data Prior to Horizontal Drilling of Gas Wells
Project Number:	2012WV178B
Start Date:	3/1/2012
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Focus Category:	Water Quality, Groundwater, Water Supply
Descriptors:	
Principal Investigators:	Jennifer Hause, Melissa J. O'Neal, Tamara Vandivort, Paul Ziemkiewicz

Publications

There are no publications.

Development of a Drinking Water Well Sampling Protocol to Establish Baseline Data Prior to Horizontal Drilling of Gas Wells

Annual Status Report
March 1, 2012 – February 28, 2013

Principal Authors:
Jennifer Hause
Tamara Vandivort
Melissa O'Neal

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Submitted by:
West Virginia Water Research Institute
385 Evansdale Drive
PO Box 6064
Morgantown, WV 26506-6064

Abstract

Recent increased use of horizontal drilling and hydraulic fracturing methods to produce natural gas from deep shale beds has raised environmental impact concerns from the general public. Although hydraulic fracturing is not a new technique to release deep deposits of natural gas, the rate of which it has been recently used, particularly within the Marcellus Shale Formation, has greatly escalated. Horizontal gas wells in the Marcellus Shale Formation differ from vertical wells due to the large water requirement for development and thus wastewater produced requiring transport and/or treatment for final disposal. Specifically of most concern are groundwater contamination issues and thus drinking water contamination concerns for those residing near active and planned shale gas well development activities.

In areas with a high level of shale gas drilling in the Marcellus Shale Formation, many homeowners claim their drinking water wells have been negatively impacted by the activities associated with developing a gas well. However, most homeowners have no data to back up their claims to confirm gas drilling has impacted their drinking water supplies. For spring and water well users, state agencies provide recommendations for pre-drilling baseline water quality testing. Industry usually takes the recommendations further by testing a more comprehensive suite of parameters. However, questions remain as to whether or not these tests are monitoring the right parameters to identify drinking water intrusion and contamination caused by nearby gas well development activities.

This study proposes to address these questions by:

1. Sampling the make-up of drilling muds and cuttings, hydraulic fracturing fluids, and flowback waters of Marcellus Shale gas wells in northern West Virginia,
2. Comparing analytical results to EPA's and States' list of contaminants of concern to identify parameters with greatest potential to be found in nearby groundwater resources,
3. Identifying potential health-related concerns associated with parameters identified as a contaminant or parameter of concern,
4. Sampling nearby private drinking water wells for contaminants of concern, and
5. Finalizing a sampling protocol for private drinking water well owners to follow that provides a level of health protection in a cost-effective and efficient manner.

Table of Contents

List of Tables

Executive Summary

As pressure for fossil fuel production grows, the proximity of residential areas to exploration and extraction operations increases along with the potential for human exposure to potential hazards and pollution. With recent increased activity tapping the gas reserves of the Devonian-aged Marcellus Shale Formation, public concern over the potential impacts of horizontal drilling and hydraulic fracturing has also increased. Although hydraulic fracturing is not a new technique, the rate of which it has been used recently in the Marcellus Shale Formation has greatly escalated bringing with it elevated concerns of environmental impacts.

Specifically of most concern are groundwater contamination issues and thus drinking water contamination concerns. Horizontal wells in the Marcellus (and other deep shale gas formations) differ from vertical wells due to the large amount of water used and thus wastewater produced; therefore, these shale gas extraction activities increase the potential to impact nearby water resources. In areas of active shale gas drilling, many homeowners claim their drinking water wells have been negatively impacted by the activities associated with developing a well site. However, most homeowners have no data to back up their claims to confirm gas drilling has impacted their drinking water supplies.

Many homeowners living in rural areas depend upon individual (private) groundwater wells as their source of drinking water. When drinking water wells are drilled, water sampling is conducted to determine if treatment prior to use is necessary. In most cases, homeowners will never have their well water tested again unless they notice a change in color, smell, taste or if industrial development begins to sprout up around them.

States provide recommendations for spring and well water users on pre-drilling baseline water quality testing. Industry usually takes the recommendations further by testing a more comprehensive suite of parameters. However, questions remain as to whether or not these tests are monitoring the right parameters to identify drinking water intrusion and contamination caused by local gas well development activities.

This study proposes to address these questions by looking at drilling muds and cuttings, hydraulic fracturing and flowback waters of Marcellus Shale gas wells and comparing the analytical results to EPA's list of contaminants of concern determining those parameters with the greatest potential to be found in groundwater sources, thus nearby drinking water wells. The need exists to narrow the list of contaminants of concern to model those parameters that are characteristic of water and waste streams associated with horizontal gas well development that pose the greatest groundwater contamination and human health impact potential, and assist with the future development of an unbiased sampling protocol for private drinking water wells that is:

- Valid, reliable and affordable to the homeowner and offers a level of protection in the event their water well becomes compromised,

- Identifies adequate baseline water quality data of groundwater supplies prior to gas well development,
- Provides a monitoring mechanism to identify upsets in water quality potentially caused by nearby gas well development by monitoring the correct water quality parameters and therefore shortens mitigation response time, and
- Develops a mechanism for the general public, industry and regulatory agencies to work together.

Introduction

Fossil fuels supply more than 85% of the nation's energy. Natural gas has a high British thermal unit (Btu) content, is an efficient and reliable energy source and is the cleanest burning of the fossil fuels (1). Reliance on natural gas as an energy source will not diminish in the foreseeable future. With recent increasing demands on energy, easily accessible oil and gas reservoirs decreasing, and success tapping unconventional natural gas resources in the United States, natural gas from unconventional resources is anticipated to become an ever-increasing portion of the country's natural gas reserves. Extraction of gas from the Marcellus Shale Formation is considered to be "unconventional" by the Department of Energy's Energy Information Administration (EIA) because the gas is found within a shale formation rather than sandstone or limestone (2).

Natural gas from unconventional resources currently accounts for nearly half of the country's total production (3). Development of the extensive natural gas reserves contained in the Marcellus Shale Formation promises to be an important opportunity for the United States because of its proximity to major markets in the northeastern United States (4 and 5). Major shale deposits under development in the United States all have the common characteristics of low porosity and permeability. Extraction from shale gas reservoirs like the Marcellus Shale Formation requires either vertical or horizontal drilling coupled with hydraulic fracturing to access and release the gas. Also required are strategies for sourcing makeup water and handling wastewater.

Advances in refining cost-effective horizontal drilling and hydraulic fracturing practices have changed the ability to tap unconventional shale reservoirs and produce a sustainable product. However, rapid application of these technological advancements has increased concern about environmental impacts from the general public as well as regulatory agencies that oversee these practices.

Drilling fluids and muds may consist of water, mineral oil or synthetic-based oil compound, weighing agents such as barite or bentonite clay, biocides, lubricants and corrosion inhibitors. The drilling process, through the use of the drilling fluids and cuttings created, increases the threat to groundwater contamination because they also have the potential to include radioactive materials. Flowback and produced water contains salts, metals and organic compounds along with the compounds introduced into the fracturing supply water such as friction reducers, surfactants, gelling agents, scale inhibitors, acids, corrosion inhibitors, antibacterial agents and clay stabilizers.

Efficient management of water streams associated with the development of a shale gas well requires knowing the characteristics of those waters. This study focuses on sampling and analyzing drilling fluids, muds and cuttings along with hydraulic fracturing and flowback waters of Marcellus Shale gas wells in northern West Virginia and determining which of these compounds if they were to reach groundwater resources are of concern for potential contamination that may affect human health. Once water and waste streams from horizontal gas wells have been characterized, a sampling protocol for monitoring nearby individual drinking water wells will be developed taking into account other sampling protocols in existence from various sources such as state agencies, private analytical service providers and industry (energy companies). The sampling protocol will be reviewed against findings of research studies that have sampled and monitored drinking water wells located in close proximity to planned and active Marcellus Shale gas wells. The sampling protocol will be revised, if necessary, and field-tested to determine if the sampling protocol will provide a cost-effective and efficient tool for homeowners to monitor water quality of their drinking water wells and detect contaminant intrusion.

Study Methods

1. Define the concerns with potential groundwater contamination that may be caused by gas well development and determine how groundwater sources are protected during the well drilling process.

2. Identify active natural gas players within northern West Virginia. Sample water and waste streams from various Marcellus Shale gas wells.

3. Compare the make-up of drilling muds and cuttings, hydraulic fracturing fluids and flowback and produced waters to the EPA's list of contaminants of concern associated with shale gas development. Determine what are the "real" indicators or "parameters of concern" to analyze based on the make-up of the water and waste streams to be sampled and input from public health officials looking at potential pollutant markers and effects these markers (parameters) have on human health.

4. Looking at basic water chemistry parameters and identified parameters of concern from this study, develop a monitoring protocol for sampling and analyzing drinking water wells located in close proximity to planned and/or active horizontal gas wells. The monitoring protocol should identify a list of parameters to analyze and how often samples should be taken during the course of planning (for baseline data), development and production (for determination if water quality changes during gas well activity) of a gas well.

5. Explore the feasibility of having sampling results added to the pre-established MonRiver Quest GIS platform or develop an independent GIS platform for this study.

Results and Discussion

Task 1: Groundwater Contamination Concerns and Marcellus Shale Gas Development

Linking the cause of contamination of a nearby drinking water well or stream to horizontal gas well development operations can be difficult. A review of literature was conducted to define potential groundwater contamination concerns that may be caused by horizontal gas well development and to identify how groundwater sources are protected during the well drilling process and related activities.

Characteristics of Drilling Waste Streams

Drilling a horizontal gas well begins the same way as other types of wells. A vertical well is drilled to a pre-determined depth, followed by the horizontal or lateral drilling into the targeted shale formation. The drilling process itself generates cuttings and muds that must be managed when removed from the bore hole. Cuttings are made up of rock fragments. Drilling muds are made up of a base fluid such as water, mineral oil, or a synthetic oil-based compound; weighting agent; clay; and a stabilizing organic material such as lignite (6). Drilling muds can also pick up characteristics of the various formations as drilling proceeds.

Cuttings are often transported from the well to the surface by the base fluid that serves to cool and lubricate the drill bit. This fluid, which is used only during the drilling phase of well development, is commonly referred to as "drilling muds" or "muds." Barite is sometimes added to the fluid for weight (7). In the Marcellus, pressurized air is commonly used as the drilling "fluid" during the vertical drilling stage and a liquid waste or slurry for the horizontal drilling stage. Drilling muds and cuttings are brought to the surface where the liquids and solids are separated via shale shaker tables that consist of large sieves (6). Liquid wastes pass through the screen and are collected in an underlying basin. The solid drill cuttings are retained on the top of the screen. Shaker tables can recover up to 70% to 80% of the liquid for reuse. Disposal options for cuttings include dewatering and haulage to a licensed waste disposal site or burial on-site with the permission of the landowner and approval from the governing regulatory body. Until recently, cuttings disposal pits were generally not lined. Muds are typically reused and sent back down the well. Once drilling is completed, muds can be reused to drill another well or be properly disposed of in a landfill.

Characteristics of Hydraulic Fracturing Fluids

After a well is drilled and casing has been placed, the completion stage, or hydraulic fracturing, begins (8). Hydraulic fracturing was first developed in the 1940s to stimulate production from oil reservoirs with declining productivity (3). In the production zone of the well, a perforation gun shoots holes through the casing and cement at pre-determined locations (9). Hydraulic fracturing takes place in stages where hydraulic fracturing fluids are pumped through the perforations, and plugs are set. The process is repeated until the length of the production zone has been fractured.

Hydraulic fracturing takes place under high pressure (around 10,000 psi) to create microfractures in the rock formation to allow the gas to be extracted. The sand or other proppant holds the new fractures open allowing the gas to flow freely out of the formation and into a production well for compression, transmission, and sale.

Mixed with the water and sand is a chemical cocktail of other ingredients that include friction reducers (slickwater), corrosion inhibitors, oxygen scavengers, scale inhibitors and biocides (disinfectants; 10). The resulting mixture is referred to as hydraulic fracturing fluid and is typically created on-site. The water and sand typically make up 98% to 99% of the hydraulic fracturing fluid with the rest consisting of the various chemical additives used to improve the effectiveness of the fracture and subsequent release of natural gas. Nearly all fluids currently used in Marcellus Shale hydraulic fracturing operations are water based or mixed slickwater fracturing fluids (5).

Some of the additives used in hydraulic fracturing fluids are used in many common household products and foods (11). However, hydraulic fracturing fluids have been found to contain hydrochloric or muriatic acid, petroleum distillate, ammonium bisulfate, fluorocarbons, naphthalene, butanol, and formaldehyde (12). Many of these chemicals are either carcinogenic or can cause a wide range of health problems affecting eyes, skin, lungs and the nervous system.

In 2010, the United States House of Representatives Committee on Energy and Commerce conducted an investigation into the practice of hydraulic fracturing in the United States (13). The investigation yielded a total of 750 different chemicals and other components used by these companies to create their hydraulic fracturing fluids. Components were found to range from harmless (table salt and citric acid), to unexpected (instant coffee and walnut hulls), to extremely toxic (benzene and lead; 13). Methanol was found to be the most widely used chemical by the companies surveyed. Methanol is considered a hazardous air pollutant and is on the candidate list for potential regulation under the SDWA (13). Other commonly used chemicals included isopropyl alcohol (surfactant), 2-butoxyethanol (foaming agent or surfactant) and ethylene glycol (scale inhibitor) along with the silicon dioxide (sand proppant). The Committee's investigation also found that the fourteen oil and gas companies surveyed used hydraulic fracturing products containing twenty-nine chemicals that are known as or may be possible human carcinogens regulated under the SDWA due to risks to human health, or listed as hazardous air pollutants under the Clean Air Act.

Each company has their own hydraulic fracturing fluid recipes and has typically kept them secret siting proprietary information (14). The resistance of energy companies to publicly disclose the chemicals used to make up their hydraulic fracturing fluids has heightened the concern that these substances can harm the surrounding environment and negatively impact human health. This is especially true if there is a way the hydraulic fracturing fluids and thus chemicals can mix with nearby groundwater resources.

Flowback Water Characteristics

Once the hydraulic fracturing process is completed and the wellbore pressure released, a portion of the fracturing fluids and water flows back up the wellbore to the well head. Referred to as flowback, this water returns over the life of the well and is collected in tanks or lined pits. The Marcellus is considered a desiccated formation. It contains little if any water in most locations. Flowback and produced water consist of organic, inorganic and radioactive compounds from the originally injected water along with constituents acquired during contact with the formation. These may include the additives that were introduced during the hydraulic fracture job as well as characteristics of the formation such as salts, oils and greases, metals and organic compounds, and may include naturally occurring radioactive materials (NORM). The primary radionuclides of concern are isotopes of radium that originate from the decay of uranium and thorium naturally present in the subsurface.

Organic compounds are either separable with de-oiling technologies (such as oils and greases) or they are soluble (such as phenol, mono-carboxylic acids glycols), requiring a more complicated removal process (15).

Radioactivity in the Marcellus Shale varies across the formation. Over time, the radioactive isotopes decay with half-lives from a few days to several hundred years. Levels of NORM in Marcellus Shale flowback tend to be relatively low with higher concentrations in the later flowback waters and produced water. Alpha particles and Radium-226 in some produced waters in New York have been found at concentrations exceeding drinking water maximum contaminant levels of 15 pCi/L and 5 pCi/L, respectively (16). The EPA has established drinking water guidelines for certain radionuclides: 5 pCi/L for radium, 30 pCi/L for uranium and 15 pCi/L for total alpha emitters. EPA has also set radium-226 levels in wastewater discharges at 60 pCi/L, discharges to land surface at 5 pCi/g and 15 pCi/g to subsurface soils.

Environmental Concerns – Drilling Related Activities

Casing and cement failure to properly bond the well annulus can result in upward migration of gas and fluids into shallow drinking water aquifers. A study conducted by researchers from Duke University found methane gas in drinking water wells located within one kilometer of active drilling sites (17). However, there was no baseline data available to determine if methane was present in the drinking water wells prior to nearby drilling activities commencing. And, methane was detected in nearly all of the drinking water wells tested regardless of the proximity to drilling activities.

A 2011 study by the Center for Rural Pennsylvania analyzed water samples from private wells within 2,500 feet of a Marcellus Shale gas well (18). Pre-drill and post-drill samples were taken to identify any changes in water quality. Samples were analyzed for TDS, chloride, sodium, sulfate, barium, strontium and methane. Results indicated there were no statistically significant increases in pollutants prominent in drilling waste fluids and the conclusion was drawn that gas well drilling had not had a significant effect on water quality of nearby drinking water wells. Nonetheless, contamination incidents attributed to poor gas well construction have occurred as presented in the Duke University study.

Horizontal shale gas wells are typically encased in alternating layers of concrete and steel down through aquifers. For wells to produce gas, it is vital there are no leaks of either gas or hydraulic fracturing fluids into aquifers or other strata. Cementing of wellbore casings need to be carried out to the surface. Down-hole pressure testing and measurements and casing integrity tests are needed to ensure protection of shallow groundwater resources. Many shale gas development operators have abandoned the use of diesel in favor of more environmentally friendly fluids such as high paraffinic fluids, mineral oil and plant-based oils that possess less toxicity and are reasonably biodegradable (19). There is also the option to use waterless fracturing agents.

<u>Environmental Concerns – Other Well Development Activities</u>

Surface activities pose an additional concern for potential groundwater contamination. Leaking pits, accidental spills or careless disposal practices of drilling fluids at the production site will increase the risk of contaminating nearby water supply wells. Storage, treatment and disposal of flowback waters also create additional water quality issues. Leaks from flowback water and waste storage pits and surface spills from transporting flowback water or hydraulic fracturing fluids can cause contamination of nearby surface water and groundwater. Onsite secondary containment is normally required to provide collection of any spillage or leakage that may occur on the drill pad. If the topography is conducive and the distance not great, natural gas developers can also use conveyance pipes to carry the various water and fluids to well pads. Depending upon the location of the well pad, this may be an option to help reduce spill potential and truck traffic.

Lined pits that are used to store the flowback water may pose a threat to groundwater and surface water resources if these structures are not designed and constructed properly to retain the liquids until they are drained and the site closed and reclaimed. Common problems with these structures include tears in liners that allow fluids to escape and enter nearby surface waters or seep into nearby groundwater. Use of double polymer liners for pits and impoundments would add an additional layer of protection to nearby groundwater and surface water resources.

Surface water contamination from the hydraulic fracturing process may occur if hydraulic fracture fluid spills at the wellhead site or if the trucks carrying this fluid leak as they travel to and from the wellhead. These spills may be from unused hydraulic fracturing fluid or return hydraulic fracturing fluid that comes back up the well during the flowback process. Spill prevention measures are necessary because surface spills may pose a greater risk to groundwater than the hydraulic fracturing process. Although operators try to ensure spills do not occur, it occasionally happens and must be reported to the proper regulatory agencies.

Blowouts are rare occurrences that happen when the fluid injected into the wellhead does not fracture the rock around the bottom of the well and the elevated pressure drives the fluid into other open and permeable pathways (20). Pathways can include the borehole, other oil and gas wells, artesian wells or abandoned wells in the vicinity that cannot handle high pressures. Blowout prevention equipment installed at the surface prevents pressurized fluids encountered during drilling from moving up the well through the space between the drill pipe and surface casing (21). Fluids spilled onto the surface from blowouts can leach into surrounding soils and groundwater and need to be cleaned up and the area remediated. Implementation of onsite secondary containment would prevent these types of fluid spills from reaching nearby surface areas.

Task 2: Identify and Sample Gas Wells

Marcellus Shale gas wells located in northern West Virginia were identified and samples were collected of water and waste streams associated with the various stages of horizontal gas well development. **Table 1** provides a breakdown of gas well site locations, water/waste stream sampling locations, gas well development stage, and number of samples collected. Eight sites in four different counties where horizontal gas well development activities are concentrated were sampled with some sites having sampling activities occur during multiple stages of well development. Samples were collected, stored, and transported to state certified laboratories following standard U.S. Environmental Protection Agency and State of West Virginia approved procedures.

Site County	# Samples	Sample Location	Well Development Stage
Water Storage			
Marshall	3	Impoundment	Freshwater
Wetzel	1	Impoundment	Freshwater
Hydraulic Fracturing (HF) Fluids			
Marion	1	Impoundment	Makeup water for HF
Marion	1	Blender sample port	Combination makeup water & fracturing chemicals
Wetzel	1	Holding tank	Make-up water
Wetzel	1	After blender	Combination makeup water & fracturing chemicals
Drilling			
Wetzel	4	Shaker table	Vertical drilling
Wetzel	1	Shaker table	Vertical drilling
Brooke	1	Shaker table	Vertical drilling
Flowback Stream /Waste Storage			
Marion	4	Condensate tank	Flowback
Wetzel	2	Separator before disposal tank	Flowback
Wetzel	1	Separator before disposal tank	Flowback
Marion	2	Pit	Waste storage
Brooke	5	Pit	Waste storage

Table 1: Horizontal Well Sites Sampled in northern West Virginia

WVWRI developed an initial list of analytes for sampling and characterizing water and waste streams associated with the various stages of horizontal gas well development. The list was based on the literature review efforts to identify commonalities among the parameters measured and previous monitoring studies conducted by WVWRI of Marcellus Shale gas wells in West Virginia and Ohio. **Table 2** details the parameter list and analytical results.

Parameter	Units	Freshwater Impoundment	HF Fluids	Drilling Muds	Drill Cuttings	Flowback	Waste Storage
Aluminum	mg/l	ND – 0.0236	ND – 0.335	0.969 – 4550	4740 – 12100	ND – 13.3	ND – 2.78
Arsenic	mg/l	ND	ND	ND – 30.6	2.35 – 19.2	ND	ND
Barium	mg/l	0.032 – 0.0565	0.61 – 12.4	2.13 – 4910	23.9 – 5920	23.1 – 2580	10.2 – 572
Bromide	mg/l	ND – 0.11	2.3 – 126	8.4 – 37.5	ND – 10.8	370 – 970	52.5 – 675
Calcium	mg/l	20.8 – 44.4	49 – 1260	1090 – 47900	781 – 152000	2310 – 19900	1010 – 8670
Chloride	mg/l	12.8- 26.5	219 – 9500	1180 – 131000	876 – 20000	27500 – 79000	4700 – 56000
Chromium	mg/l	ND	ND	0.268 – 16.2	6.367 – 32.8	ND – 0.068	ND – 0.144
Iron	mg/l	ND – 0.0244	0.174 – 30.9	1.09 – 13600	6670 – 30400	14.7 – 149	19.3 – 57
Lead	mg/l	ND	ND	ND – 84.9	3.5 – 31.5	ND – 0.102	ND
Magnesium	mg/l	4.04 – 8.24	6.85 – 171	2.84 – 2410	1920 – 7090	436 – 2260	107 – 944
Manganese	mg/l	0.0025 – 0.022	0.147 – 1.76	0.064 – 435	91.9 – 714	1.74 – 10.2	1.38 – 7.56
Mercury	mg/l	ND	ND	ND – 0.196	ND – 0.173	ND	ND
Nickel	mg/l	ND	ND	ND – 37.7	10.3 – 41.4	ND	ND
Phosphorus	mg/l	ND – 0.04	0.09 – 11.2	0.6 – 235	100 – 349	ND – 2.36	0.75 – 90
Potassium	mg/l	1.61 – 2.92	2.32 – 63.6	465 – 24900	1930 – 12000	211 – 488	44.2 – 315
Selenium	mg/l	ND	ND	ND – 3.34	ND – 3.14	ND – 0.335	ND
Silver	mg/l	ND	ND	ND – 0.509	ND – 0.397	ND	ND
Sodium	mg/l	8.46 – 27.1	110 – 3990	364 – 44900	543 – 12400	15900 – 119000	2440 – 20800
Strontium	mg/l	0.122 – 0.239	3.92 – 136	10.6 – 839	4.22 – 508	657 – 4660	117 – 1460
Sulfides	mg/l	4.19 – 30.3	4.47 – 33	638 – 9450	1410 – 12800	ND – 303	ND – 38.7
Zinc	mg/l	ND – 0.0075	ND – 1.74	ND – 94.8	2.22 – 89.7	ND – 0.288	0.06 – 0.352
Conductivity	µmhos/cm	315 – 483	1030 – 33100	13200 – 222000	1150 – 77000	74900 – 225000	16800 – 132000
pH		8.09 – 8.75	6.63 – 7.96	7.35 – 12.71	NM	6.49 – 7.07	6.16 – 7.82
Hardness (total)	mg/l	68.4 – 142	150 – 3840	2740 – 6550	NM	196 – 59000	2950 – 25500
Alkalinity (total)	mg/l	48.2 – 188	49.3 – 188	220 – 11100	209 – 54700	139 – 255	118 – 234
TDS	mg/l	170 – 277	568 – 20400	6600 – 119000	NM	45400 – 154000	8840 – 93700
TSS	mg/l	ND – 6	14 – 260	18300 – 162000	NM	ND – 348	143 – 420
Methane	µg/l	ND	ND – 265	ND	NM	1.81 – 8310	187 – 10500
Ethane	µg/l	ND	ND	ND	NM	ND – 2730	ND – 1760
Propane	µg/l	ND	ND	ND	ND	ND – 1130	ND
TOC	mg/l	0.72 – 5.4	4.55 – 217	1050 – 60000	26700 – 82100	3.36 – 588	25.8 – 309
COD	mg/l	12 – 19	31 – 1110	3290 – 11200	526 – 5290	743 – 2660	568 – 2280
Oil & Grease	mg/l	ND	ND – 20.4	ND – 196	ND – 5.13	ND – 39.1	4.6 – 594
Benzene	µg/l	ND	ND – 29.4	ND – 300	ND – 294	ND – 716	ND – 372
Toluene	µg/l	ND	ND – 76.9	ND – 2160	ND – 1640	ND – 2470	ND – 2070
Ethylebenzene	µg/l	ND	ND – 8.7	ND – 513	ND – 404	ND – 220	ND – 235
Xylene (o,m,p)	µg/l	ND	ND – 165.5	ND – 5610	ND – 3164	ND – 4053	ND – 3097
Styrene	µg/l	ND	ND	ND – 9.5	ND	ND	ND – 141
Tetrachloroethylene	µg/l	ND	ND	ND	ND – 63.3	ND	ND
MBAS	mg/l	ND – 0.177	ND	ND – 262	NM	ND – 0.605	ND – 0.473
TPH (diesel)	mg/l	ND	ND – 119	23.1 - 237000	115 - 55900	0.57 – 114	1.9 – 285
Gross Alpha	pCi/l	NM	1.2 – 9.43	3.78 – 173	8.93 – 28.3	18.9 – 20920	8.69 – 5304
Gross Beta	pCi/l	1.48 – 2.25	9.89 – 83	14.9 – 23770	17.3 – 30.1	168 – 4664	34 – 1349
Radium-226	pCi/l	0 - .725	NM	6.45	0.95 – 3.114	178 - 685	15.4 – 1194
Radium-228	pCi/l	0.189 – 0.354	NM	4.95	0.715 – 1.929	49.1 – 85.5	53.5 - 216

ND = not detected NM = not measured

Table 2: Horizontal Gas Well Water and Waste Stream Analytical Results (ranges presented)

WVWRI's objective is to provide a cost-effective monitoring protocol that provides the level of health and environmental protection desired by the consumer.

Task 3: Identify Pollutant Markers and Define Water Well Testing Protocol

A review of drinking water supply studies and various state guidelines for water well testing yielded a fairly comprehensive water quality parameter list with over sixty inorganic, organic, and radioactive parameters. Water and waste stream characterization results allowed WVWRI to consider elimination of parameters that were not detected. Comparing these results to the literature review yielded a listing of water quality parameters (pollutant markers) to serve as the basis for development of a drinking water well monitoring protocol to be evaluated during this study, see **Table 3**.

	Parameter			
Inorganics	Silver	Aluminum	Arsenic	Barium
	Bromide	Calcium	Chloride	Iron
	Mercury	Magnesium	Manganese	Sodium
	Nickel	Lead	Potassium	Selenium
	Sulfate	Strontium	Zinc	Total Hardness
	Total Alkalinity	Total Dissolved Solids	Total Suspended Solids	
Organics	Oil & Grease	BTEX	Surfactants (MBAS)	TPH (diesel, oil, gas ranges)
Radionuclides	Gross Alpha	Gross Beta	Radium-226	Radium-228

Table 3: Water Quality Parameters of Concern based on Literature Review

WVWRI staff will next begin to compare the results of the chemical makeup of drilling muds and cuttings, hydraulic fracturing fluids and flowback and produced waters to the EPA's contaminants of concern list. WVWRI staff will also seek the assistance of public health professionals within WVU's School of Public Health (SPH) to evaluate the sampling results and comparison with EPA's contaminant of concern list to further define potential pollutant markers. The WVU SPH has provided a preliminary listing of potential pollutant markers for testing drinking water wells, see **Table 4**.

	Parameter			
Inorganics	Aluminum	Antimony	Arsenic	Barium
	Bromide	Cadmium	Chloride	Chromium
	Copper	Iron	Lead	Magnesium
	Manganese	Nickel	Sodium	Strontium
	Sulfate	Zinc	Conductivity	Salinity
	Total Dissolved Solids			
Organics	Methane	Ethylene	Propylene	Xylene
	Benzene	Toluene	Aldehydes	Naphthalene
	Ethylene glycol	Diethylene glycol	2-butoxy ethanol	TPH (gas & diesel)
Radionuclides	Uranium			

Table 4: Initial Recommendation of Pollutant Markers

WVWRI will continue to work with WVU SPH to refine their monitoring recommendations. The results of the collaboration with public health officials will yield a list of parameters with the greatest potential to be found in nearby groundwater resources and potential health-related concerns associated with each of the parameters. This list will become part of the sampling protocol that will then be field-tested. Results will allow for WVWRI staff to revise the protocol as necessary and to finalize a product to make available via our website. Once the protocol is finalized, WVWRI will explore the feasibility of adding sampling results as an additional layer to the 3RQ (originally MonRiver Quest) GIS platform. Sampling results will be either submitted to WVWRI for downloading or directly downloaded to the platform by the user.

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Publications

Work is ongoing. Once sampling and monitoring protocol has been finalized, WVWRI will submit abstracts and papers to relevant publications and conferences for consideration.

Information Transfer Program

Once the sampling and monitoring protocol is finalized, WVWRI will explore the feasibility of adding sampling results as an additional layer to the 3RQ (originally MonRiver Quest) GIS platform. Sampling results will be either submitted to WVWRI for downloading or directly downloaded to the platform by the user.

Student Support

Two graduate students, one full-time and one part-time, will be starting June 2013 to finalize the monitoring protocol, identify sampling sites, and collect drinking water well samples to evaluate the of the testing protocol. Based on the results, the protocol will be adjusted to provide a plan for private drinking water well owners to follow that offers health protection in a cost-efficient and effective manner.

Notable Achievements and Awards

No awards to report at this time.

Stable isotope fingerprinting of waters in area of accelerating Marcellus shale gas development

Basic Information

Title:	Stable isotope fingerprinting of waters in area of accelerating Marcellus shale gas development
Project Number:	2012WV197B
Start Date:	3/1/2012
End Date:	2/28/2014
Funding Source:	104B
Congressional District:	
Research Category:	Water Quality
Focus Category:	Groundwater, Surface Water, Water Quality
Descriptors:	
Principal Investigators:	Shikha Sharma, Shikha Sharma

Publications

1. Sharma, S., M. Mulder, A. Sack, K. Schroeder, R. Hammack. 2013. Isotope approach to assess hydrologic connections during Marcellus Shale drilling. Groundwater. (Under review.)
2. Pelak, A. and S. Sharma. Stable isotopic and geochemical analysis of surface waters in an area of Marcellus Shale development in north-central West Virginia. Hdrologic Processes. Hydrologic Sciences. (In preparation.)

Project Report title: Stable isotope fingerprinting of waters in an area of accelerating Marcellus shale gas development

Type of report: Annual
Reporting period: February 2012-March 2013

Summary

The main concern associated with Marcellus shale gas development is that water quality of surface waters and fresh water aquifers can be compromised during gas well drilling, stimulation, and improper disposal practices. Under natural conditions the highly saline groundwater occurring within Marcellus shale and other deep formations does not mix with shallow fresh water aquifers due to the barrier provided by several thousand feet of impermeable rocks present between the two end-members. However, during well drilling casing or grouting failures, existing subsurface fractures, and fractures created during hydraulic fracking can generate or augment hydraulic pathways between previously isolated formations. These pathways can allow frack water, deep saline water or methane to contaminate shallow fresh water sources. In addition, improper management and disposal of frack flowback water can deteriorate the water quality of surface water bodies and shallow groundwater aquifers in the area. In order to effectively assess the effect of Marcellus shale development on water quality there is a need to establish the background or ambient geochemical signatures of different water sources. In addition, there is need to develop a suite of natural geochemical tracers that can track the flowback waters and dissolved methane in the groundwaters or surface waters of the area.

The aim of this project is to test the applicability of isotopic composition of water ($\delta^{18}O_{H2O}$, δD_{H2O}) dissolved inorganic carbon ($\delta^{13}C_{DIC}$), and dissolved sulfate ($\delta^{34}Sso_4$, $\delta^{18}Oso_4$) as natural tracers to identify any potential water quality deterioration associated with Marcellus Shale drilling in North Central West Virginia. The main tasks undertaken in collaboration with WV Water Science Center during this year of this grant were:

1) Characterization of O,H,C, and S isotope composition as well as major, minor, and trace metal geochemistry of surface waters (sampled by 50 streams) overlying the Marcellus shale in north central West Virginia
2) Evaluation and comparison of 5 categories of Marcellus Shale production of surface water samples.

Preliminary data indicates that O,H and C stable isotope compositions of produced/flowback water from wells drilled in Upper Devonian sands and Marcellus Shale can be used to distinguish different water sources indicating the promise of this approach to identify potential contamination ensuing from shale gas drilling activities in future. The preliminary paper summarizing this approach has been accepted with minor revisions.

Experimental Methods

Water samples were collected from 50 streams in the Monongahela River basin of north-central West Virginia. Sample locations were chosen by analyzing all of the HUC-12 watersheds that comprise the Monongahela River basin and determining the extent of Marcellus Shale production that has occurred to date. 5 categories were created to represent the differing amounts of production present in the basin. The number of samples for each category was chosen by analyzing the production status for all HUC-12's in the basin, and then determining a representative number of samples for each category out of a total of 50 samples. Table 1 shows the ideal number of sites, available number of sites, and the actual number of sites chosen for the study. Figure 1 shows the study area and sample locations.

	Ideal # of Sites	# of Sites Available	Number of sites chosen
High Prod.	9	18	12
Low Prod.	7	7	5
No Production	15	13	9
Near HP	7	9	12
Near LP	12	12	12

Table 1: Ideal numbers of sites, available sites, and actual number of sites chosen

The production categories are defined as follows:

· **High production** -> HUC-12 that contains Marcellus shale development that produces greater than 1,000 MCF/mi2/year

· **Low production**, ->HUC-12 that contains Marcellus shale development that produces less than 1,000 MCF/mi2/year

· **Near high production** -> adjacent to high production HUC-12

· **Near low production**, -> adjacent to low production HUC-12

· **No Production** -> Underlain by Marcellus shale greater than 50 feet thick, no Marcellus Shale production in or adjacent to HUC-12.

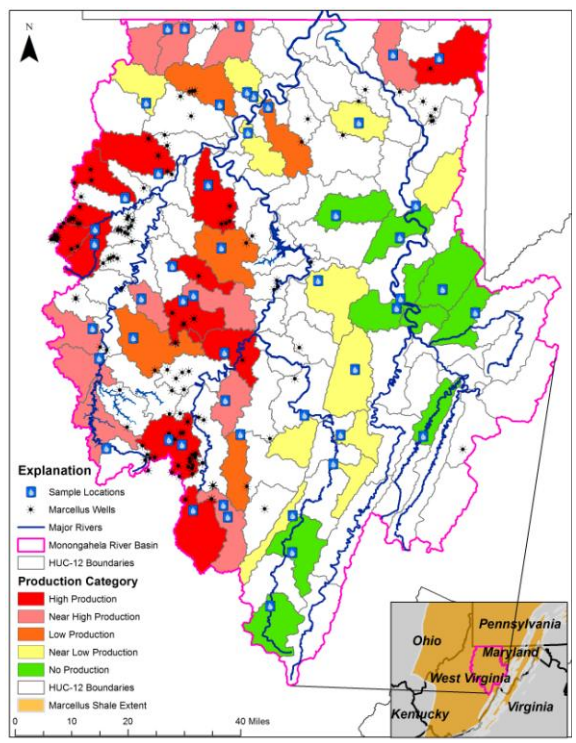

Figure 1 – Study area and sample locations

Water samples were collected from 50 surface water samples sites in the Monongahela River basin of north-central West Virginia. All samples were collected when streams were at base flow to ensure that all streamflow contributions were from groundwater discharge. The width and depth of each stream sample site was first measured, and then a width integrated sample was collected in an open mouth hand-held bottle and placed in a churn carrier. The churn carrier was filled with approximately 8 liters of water from the sample location so that all of the water in the churn was representative of all of the water in the stream. Width integrated collection of field parameters (pH, specific conductance, Eh, temperature, total dissolved solids, dissolved oxygen, and turbidity) were collected with an YSI 6820 V2 Sonde at each stream. Average field conditions of each stream were calculated using the width collected field parameters. Field alkalinity was calculated at each sample site using a standard titration with nitric acid. All geochemical and isotope samples were pulled from the width integrated sample in the churn carrier. One isotope sample was collected for $\delta^{2}H$ and $\delta^{18}O$ of water, one sample for $\delta^{13}C_{DIC}$ of dissolved inorganic carbon, and one sample for $\delta^{34}S$ and $\delta^{18}O$ of dissolved sulfate. All isotope samples were refrigerated until analysis was performed.

Samples for $\delta^{2}H_{H2O}$ and $\delta^{18}O_{H2O}$ were pulled from the width integrated sample in the churn carrier and placed in an 8 mL pre-rinsed glass threaded vial with no headspace. Random duplicate samples were taken for quality control purposes. Vials were wrapped with parafilm to ensure no leakage took place. Samples for $\delta^{13}C_{DIC}$ were pulled from the width integrated sample in the churn carrier and collected in a triple pre-rinsed 60 mL syringe. Samples were then filtered through Cameo 0.45 µm nylon pre-filter into a 10 mL Wheaton serum vial with no headspace. 1-2 drops of benzalklonium chrloride (17% w/w) were then added to the 10mL vial before the filtered water was added to halt any metabolic activity. $\delta^{34}S$ and $\delta^{18}O$ samples for dissolved sulfate were collected in a 1L pre-rinsed high density polyethene bottle. Water samples were then filtered using a vacuum pump through a 45mm 0.4 µm PCM filter and placed back in the original bottle. During filtration a glass petri dish was placed over the water to prevent oxidation of sulfide to sulfate. Prior to placing water back in to the original bottle, the bottle was triple rinsed with DI. Filtered water samples were then shipped to IsoTech Laboratories where further sample prep will be done, which includes precipitation of $BaSO_4$ power for isotopic analysis.

The O,H and C isotopic composition were analyzed at the Stable Isotope Laboratory at WVU (WVSIL) using a Finnigan Delta Advantage continuous flow isotope ration mass spectrometer (IRMS) with the ThermoQuest Finnigan GasBench II device. Each sample is flushed using the PAL autosampler system, equilibrated for 24 hours, and then sampled with PAL system. The headspace is analyzed using a double-needle; while the carrier gas is being injected continuously into the sample vial through one slit, the other removes headspace evacuated by the gas. Duplicate samples of 10.0 µL are taken over the course of 60 seconds with a total 10 replications for each sample. From there, the head space sample is carried through the components of the IRMS via the carrier gas through the GasBench. Internal lab standards are incorporated in triplicates in the beginning, middle (if a high number of samples), and end of each run sequence for QA/QC checks. These internal standards are calibrated against the respective IAEA international standard. Samples for C and H isotope of methane and S isotope of sulfate were shipped to Isotech Laboratories for analysis.

Samples for analysis of major ions, and trace elements were shipped to the National Water Quality Laboratory. Sodium, calcium, magnesium, strontium, potassium, iron, manganese, boron, and silica are analyzed by inductively coupled plasma atomic emission spectroscopy (ICP-EAS). Sulfate, chloride, and bromide are analyzed by iron chromatography (IC). Fluoride is analyzed by inhibited spontaneous emission (ISE) and TDS by residue on evaporation (ROE). Trace elements of aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, lead, molydbdenum, nickel, selenium, silver, uranium, and zinc are analyzed by inductively coupled plasma mass spectroscopy (ICP-MS) or cICP-MS. Samples for radiochemistry were shipped to Eberline Services.

Results and Discussion

Water geochemistry and isotopic composition

Results from major ion hydrochemistry show wide variations in the surface water samples. Analyses were grouped by production category to determine if there were any significant differences between the categories. There were no clear differences between the categories, while there were 4 distinct water facies present. The water facies were $Ca\text{-}SO_4$, $Ca\text{-}HCO_3$, $Na\text{-}HCO_3$, & $Na\text{-}SO_4$. The main processes affecting the hydrochemistry of the samples are hypothesized to be carbonate dissolution, silicate weather, and pyrite oxidation.

Oxygen and hydrogen isotopes in the samples fall along the LWML. The higher *d*-excess values in the surface waters are interpreted to be a result of dominant recharge being sourced by recycled moisture in air masses originating above the Great Lakes area. The original air masses are subjected to high rates of evaporation over the water bodies, of which the evaporative vapor is mixed with atmospheric. In conjunction with local processes such as altitude and latitude, the isotopic signatures of δ^2H_{H2O} and $\delta^{18}O_{H2O}$ plot above the GMWL in the area of an arid vapor mass.

Carbon isotopes of DIC show deviation from the range of natural waters. Enriched values of $\delta^{13}C_{DIC}$ are predominantly the result of carbonate and carbonaceous shale weathering, evident through hydrochemical relationships. Sulfur isotope compositions in dissolved sulfate can indicate the source of sulfur, shown to be ranging from coals, shales, and pyrite. The depleted carbon signatures may be indicative of sulfate reduction, but was not confirmed through the isotopic analysis of $\delta_{34}S_{SO4}$ with $\delta^{18}O_{SO4}$ or $\delta^{13}C_{DIC}$ due to the origin of the oxygen atom and variations in carbon input in DIC. The depletion seen in $\delta^{34}S_{SO4}$ is a preliminary indication of sulfide oxidation. Overall variation, both in hydrochemistry and isotopic signatures, differed widely between and within each production category. Seasonal sampling should be done in order to understand the variations that are naturally present in surface waters.

The hydrochemical and isotopic variations in the area surface waters in this study in addition to a previous study of groundwater done last year provide the basis for prospective studies regarding the water quality of north-central West Virginia as shale gas exploration is expanding. If surface waters are exposed to significant contributions of flowback/produced water from natural gas drilling, the established baseline isotopic signatures will dramatically change. This occurrence will distinctly shift the ambient signatures and hence serve as a natural fingerprint to determine if aquifers are receiving significant contribution from flowback waters. Accordingly, this study provides the foundation for geochemical assessment of water quality issues related to Marcellus Formation gas development in the study area.

Conclusions

The O, H, and C isotope composition of waters collected from streams during base-flow conditions in areas of different stages of Marcellus Shale production show no prominent differences. The hydrochemical analyses also indicates no significant contribution from flowback waters associated with Marcellus Shale operations in the area. This indicates that these surface waters are not receiving any significant input from produced waters associated with Marcellus Shale drilling or the contribution is so small that it cannot be detected using this isotopic approach.

Publications, Posters, and Talks

1. Sharma S., Mulder M., Sack A., Schroeder K., Hammack R. 2013. Isotope approach to assess hydrologic connections during Marcellus Shale drilling. Groundwater (acceptance stage)
2. Pelak A. and Sharma S. Stable isotopic and geochemical analysis of surface waters in an area of Marcellus Shale development in north-central West Virginia. Hydrologic Processes. Hydrologic Sciences (in prep)
3. Sharma S., 2012. Use of stable isotopes in shale gas research: examples from the Appalachian Region of eastern USA. International Workshop on Exploration and Exploitation of Shale Gas, National Geophysical Research Institute, Hyderabad, 19-20 December, Hyderabad, India.
4. Sharma S., Mulder M.L. Sack A., Carr T., Schroeder K., Hammack, R., White, J., Chambers D., 2012. Isotopic fingerprinting of stray gas in area of accelerating shale gas development in the Appalachians. WV Water Conference, 30-31 October , Morgantown, WV.
5. Sharma S., Mulder M.L. Sack A. , Bowman, L. , Carr T., Schroeder K., Hammack, R., White, J., Chambers D. 2012. Understanding natural variations of dissolved methane in areas of accelerating Marcellus Shale gas development. GSA National Annual Meeting 4-7 November, Charlotte, NC.
6. Pelak A., Sharma S., Chambers D., White J., 2012. Spatial analysis of stable isotopic variations in surface waters of an area of accelerating Marcellus shale development in north-central West Virginia**.** GSA National Annual Meeting 4-7 November, 2012 Charlotte, NC.
7. Pelak, A., and Sharma S., 2012. Comparison of stable isotopic variations in surface waters in five stages of Marcellus shale development in the Monongahela River basin of north-central West Virginia. WV Water Research Conference, October, 30, 2012. Morgantown, WV.

Student Support

1 MS student Michon Mulder graduated in May 2012

MS theis: " *Ambient Geochemical and Isotopic Variations in Groundwaters Across an Area of Accelerating Shale Gas Development*

1 MS student: Adam Pelak - graduating Summer 2013

MS thesis : *"Stable isotopic and geochemical analysis of surface waters in an area of Marcellus Shale development in north-central West Virginia"*

Notable Achievements and Awards

- 2 MS Thesis supported by 2 year funding (1 student graduated and other to graduate this summer)
- 1 research paper in final acceptance stage in journal Groundwater and one paper in preparation
- Results presented in several regional/national/international conferences
- Research highlighted in several university and regional magazines and articles

Modeling the hydrologic response in surface mining watersheds with redesigned reclamation practices

Basic Information

Title:	Modeling the hydrologic response in surface mining watersheds with redesigned reclamation practices
Project Number:	2012WV200G
Start Date:	9/1/2012
End Date:	8/31/2015
Funding Source:	104G
Congressional District:	First
Research Category:	Engineering
Focus Category:	Hydrology, Models, Management and Planning
Descriptors:	None
Principal Investigators:	Leslie Hopkinson, Ben Mack, John D. Quaranta

Publications

There are no publications.

Annual Report

Title:	Modeling the hydrologic response in surface mining watersheds with redesigned reclamation practices
Reporting Period Start Date:	09/01/2012
Reporting Period End Date:	02/28/2013
Principal Authors:	L. Hopkinson, J. Quaranta, B. Mack
Date Report Issued:	05/16/2013
USGS Award Number:	G12AP20156

Table of Contents

1. Research

The goal of this research is to evaluate the potential application of geomorphic design in surface mining reclamation, focusing on the water supply in Central Appalachia. Specific objectives include the following:

- Obj. 1: Generate geomorphic valley fill designs.
- Obj. 2: Determine the hydrologic function of a redesigned valley fill site in southern West Virginia.
- Obj. 3: Predict differences in floodplain mapping downstream of redesigned reclamation, resulting from extreme meteorological events.
- Obj. 4: Predict the hydrologic response of watersheds with redesigned reclamation at the landscape scale.

In this reporting period, there was technical progress for objectives 1 and 2.

Specific technical progress is outlined in the following sections. Students have been identified to begin working on objectives 3 and 4. Work on these objectives will be initiated in the next reporting period.

Obj. 1. Generate geomorphic valley fill designs

This work builds upon previous work that began the process of creating geomorphic landform designs for valley fills. In that previous work, the process for creating regional geomorphic landform designs for Central Appalachia valley fills was developed (Sears et al., 2013; Buckley et al., 2013, Sears et al., in review).

For this project, the first of three designs were created for a permitted valley fill currently under construction (Fig. 1). Surface water runoff retention structures were included in this design. The design was created to consider wildlife and vegetation benefits as well as potentially create perennial stream channels on the site. Three valley ponds (constructed on the surface of the land) were included in the regional valley-fill design that satisfied the drainage density requirements (Fig. 1). These structures will be used to retain surface water runoff, create wetland areas, and discharge water year-round to create perennial stream flow. Figure 2 illustrates a close-up of one of the created valley ponds. Next, bench ponds will be added (land is removed to create pond) on the created geomorphic landform design (GLD) with regional data. The bench ponds will be used as created wetlands to improve wildlife and vegetation habitat on the valley fill. This design will be completed by early summer.

Currently, we are performing a literature review to obtain information on accurately sizing surface water retention structures and vital properties of successful man-made wetlands. This critical information will be used to improve the regional GLDs and the surface water retention structures.

After completing the water retention GLDs, a retrofit design will be completed that will incorporate geomorphic landform principles on previously constructed traditional valley fills. The retrofit design will improve these structures while creating a natural habitat with stream channels, ridges, and valleys. The retrofit GLD will also be modeled using Carlson's® Natural Regrade® with GeoFluv™ software. This design will be completed within the next three months and will have the potential to improve formerly constructed valley fills by improving wildlife habitat, vegetation diversity, and surface water runoff control.

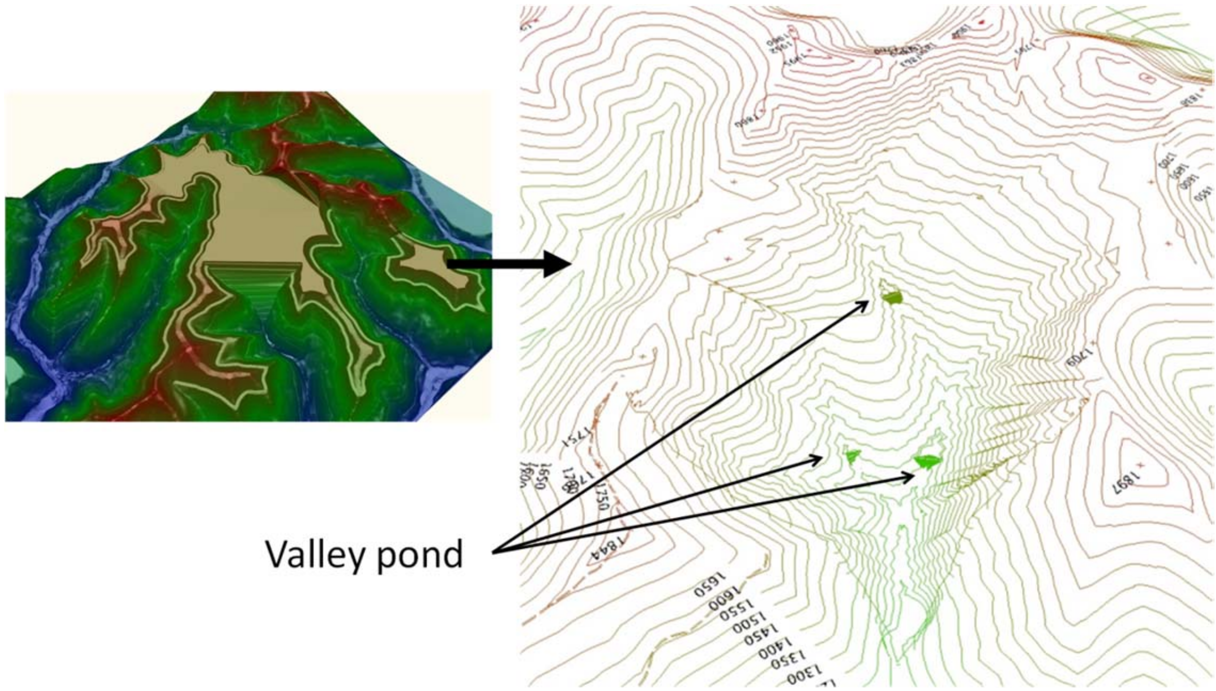

Figure 1: GLD with Regional Data and Valley Ponds

Figure 2. Valley pond, close-up view

Obj. 2. Determine the hydrologic function of a redesigned valley fill site in southern WV

Curve numbers are being calculated for mined areas in southern West Virginia. Differences in the hydrologic response of the design alternatives are being predicted through modeling. This work will be expanded to a M.S. thesis with expected publication of fall 2013. Preliminary results are presented in this report.

Curve Number Evaluation: Curve numbers were calculated for three watersheds in southern WV that had varying levels of mining activity. The watershed data used to calculate the curve numbers of watersheds with active MTRM was acquired from stream gauge stations maintained by the USGS. Hydrograph data provided by the stream gauges were used to calculate the amount of runoff generated by selected 24-hour storm events. The precipitation values of these storm events were acquired from the National Oceanic and Atmospheric Administration (NOAA) website. The values calculated for this research (Table 1) are compared to published values in Table 2.

Table 1: Calculated Curve Numbers (CN) for watersheds with varying degrees of mining

Watershed	Area (mi^2)	Description	CN
Panther	31	Undisturbed	65-72
Clear Fork	62.7	7% MTRM	67-81
Laurel Creek	33	9% MTRM	70

Table 2: Curve numbers (CN) for watersheds impacted by MTRM

Reference	Location	Condition	NRCS Reference Condition	CN
Talyor et al., 2009	KY	Reclaimed Mine Site	-	60- 90
Warner et al., 2010	KY	Reclaimed Mine Site	-	62-94
Bonta et al., 1997	OH	Reclaimed Mine Site	-	87-97
Ritter and Gardner, 1991	PA	Reclaimed Mine Site	-	72-89
Permit S-5008-09	WV	Pre-Mining/Undisturbed	Woods – Poor – B	66
-	-	Active mining/not seeded or mulched	Dirt – Poor – B	82
-	-	Reclamation > 5 yrs	Brush/Weed/Grass Mixture – Poor – B	67
-	-	Reclamation < 5 yrs	Pasture – Fair – B	69

Hydrologic Response: To date, the hydrologic response of the original topography and first GLD iteration have been completed (Figure 3). Aquaveo's Watershed Modeling System (WMS) software was used to model watershed attributes and the hydrologic response of the various topographies. The hydrologic response of the watershed was modeled for 1-, 2-, 5-, 10-, 25-, 50-, 100-, and 500-year storm events. We are currently modeling the GLD that incorporates surface storage and will compare the results of this modeling to the conventional valley fill case.

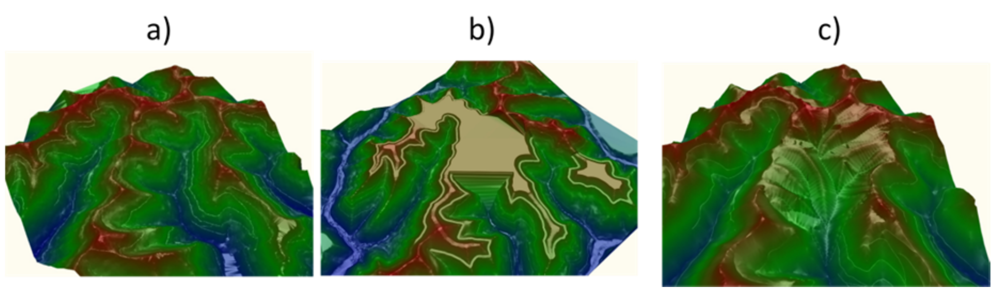

Figure 3. a) original topography, conventional fill, geomorphic landform design for permitted location

Original Topography: First, the hydrologic response of the undisturbed topography of the permitted site was evaluated (Figure 3a). The watershed was delineated (Figure 4) and the hydrologic response of the watershed was modeled using TR-55. The watershed was modeled using curve numbers (CN) of 55, 50, and 66. These numbers correspond to the various hydrologic soil conditions of a forested watershed within the hydrologic soil group (HSG) B as provided by the NRCS TR-55 literature (Table 1).

CN values of 55, 60, and 66 were used to account for the dynamic nature of the curve number within watersheds. Table 2-2c from the NRCS Technical Release 55 *Urban Hydrology for Small Watersheds* (USDA 1986) provides a CN of 55 for soil within the "B" hydrologic soil group (HSG) that is considered to be in "Good" hydrologic condition. This should provide an estimate for a "best-case" scenario in which a given storm-event is most likely to produce the smallest amount of surface runoff. The CN value of 60 represents a forested watershed of soil type "B" under fair condition and the CN value of 66 represents a "worst-case" scenario where a given storm-event is most likely to produce the largest amount of surface runoff in a forested watershed. A surface water runoff analysis of the mine site prepared by a consulting company present in the permit files also used a CN value of 66. These results will be used to compare the runoff volume and peak discharge data generated by the models generated in WMS. Runoff data was generated using 1-, 2-, 5-, 10-, 25-, 50 -, 100-, and 500-year 24-hour precipitation amounts. Table 3 below lists the 24 hour rainfall amounts for West Virginia as gathered from the NRCS database within TR-55 for a Type II distribution.

Table 3: WV precipitation data

Rainfall Return Period (yr)	24 - Hr Rainfall Amount (in)
1	2.3
2	2.7
5	3.4
10	4
25	4.7
50	5.0
100	5.5
500	6.6

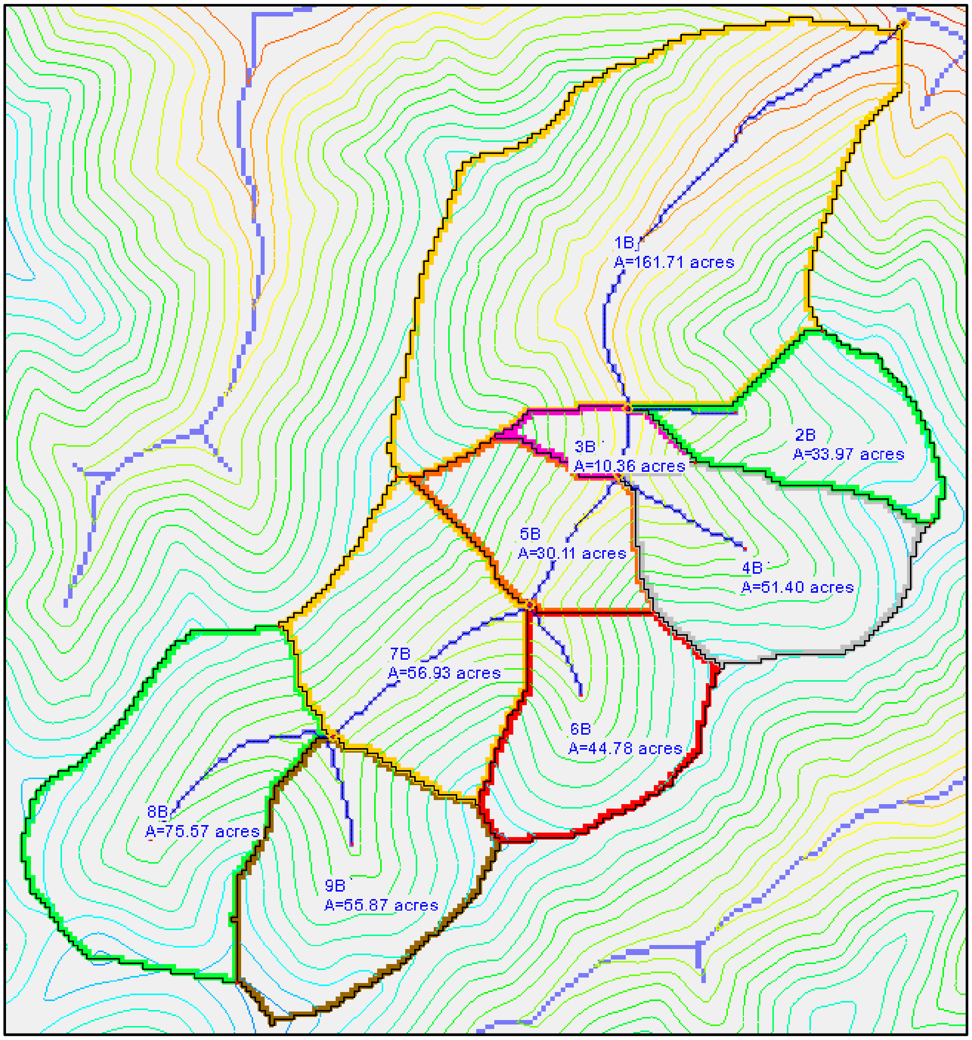

Figure 4: Original topography delineated watershed and watershed sub-basins

The watershed is composed of nine sub-basins ranging in area from 10.4 to 162 acres with an average area of 57.9 acres. Table 4 displays the area, basin slope, basin length, maximum flow distance (MFD), maximum flow slope (MFS), and maximum stream slope (MSS) of the nine sub-basins within the original topography watershed. These data will be compared to basin data gathered from the AOC variance topography and the geomorphic landform designs.

Table 4: Original topography basin data

	1B	**2B**	**3B**	**4B**	**5B**	**6B**	**7B**	**8B**	**9B**
Area (ac)	162	34.0	10.4	51.4	30.1	44.8	56.9	75.6	55.9
Basin Slope	0.56	0.44	0.56	0.49	0.56	0.50	0.53	0.47	0.48
L (ft)	4,793	2,317	949	2,218	1,459	1,672	1,761	2,387	2,071
MFD (ft)	5,321	2,601	1,127	2,587	2,316	2,044	2,374	2,907	2,341
MFS	0.16	0.32	0.47	0.32	0.31	0.34	0.28	0.22	0.29
MSS	0.06	0.35	0.03	0.24	0.06	0.18	0.07	0.11	0.11

Table 5 shows the TR-55 data for the watershed outlet for the 1- through the 100-year storm events for a CN of 66. The maximum peak discharge and maximum discharge volume were seen at the 500-year return period storm event at 1221 cfs and 54.2 x 10^5 ft^3, respectively.

Table 5: Hydrograph data for outlet of original topography for CN = 66

T **(yr)**	Q_p **(cfs)**	t_p **(min)**	V **(ft^3 x 10^5)**
1	54.0	738	4.69
2	104	738	7.34
5	245	738	13.8
10	398	738	20.4
25	579	738	28.0
50	677	738	31.9
100	848	738	38.7
500	1221	732	54.2

*T =return period; Q_p = peak discharge, t_p = time to peak, V = runoff volume

The watershed response at a CN of 60 is shown in Table 6 below. At a CN equal to 60, the peak discharge and discharge volume experienced at the watershed outlet decreased by an average of 29% and 20%, respectively, when compared to the discharges at a CN equal to 66. The maximum reduction occurred at the 1-year storm event, which saw a decrease in peak discharge of 66% from 54 cfs to 13.8 cfs. The discharge volume fell 51%, from 4.69 x 10^5 ft^3 to 2.29 x 10^5 ft^3.

Table 6: Hydrograph data for outlet of original topography for CN = 60

T **(yr)**	Q_p **(cfs)**	t_p **(min)**	V **(ft^3 x 10^5)**
1	13.8	768	2.29
2	35.1	744	4.09
5	116	738	8.92
10	226	738	14.3
25	364	738	20.7
50	434	738	24.1
100	560	738	30.0
500	861	738	43.6

*T =return period; Q_p = peak discharge, t_p = time to peak, V = runoff volume

Table 7 displays the TR-55 outlet data for the watershed at CN = 55. The average decrease between the outlet peak discharge at CN = 60 and CN = 55 was 44% with the maximum difference occurring at the 1-year return period with a 67% reduction in flow. The average difference between total discharge volumes was 33% with the maximum difference occurring at the 1-year return period with a 57% reduction in volume.

Table 7: Hydrograph data for outlet of original topography for CN = 55

T (yr)	Q_p (cfs)	t_p (min)	*V* (ft^3 x 10^5)
1	4.57	780	0.986
2	12.0	768	2.16
5	51.7	744	5.64
10	122	738	9.90
25	228	738	15.2
50	290	738	18.1
100	404	738	23.3
500	667	738	35.3

**T* =return period; Q_p = peak discharge, t_p = time to peak, *V* = runoff volume

The storm response hydrograph (Figure 5) illustrates the watershed response to a 2-year storm at CN values of 66, 60, and 55. With the Type II rainfall distribution selected within TR-55 for every test the hydrographs would all be expected to have the same shape. Figure 5 shows that the hydrographs all have the same shape and follow the same pattern. It should be noted that the peak times of the storm response hydrographs vary between 738 minutes for CN = 66 and 780 minutes for CN = 55. This could be due to increased initial infiltration of rainfall at lower CN values, which would result in an increase in the time of peak discharge (NRCS, 1986).

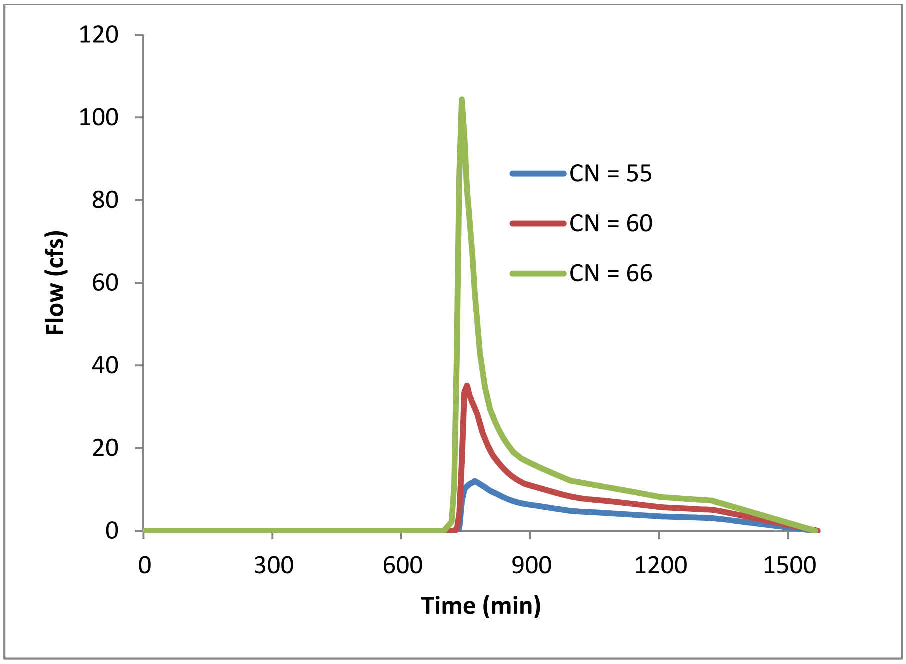

Figure 5: Storm response hydrograph for a 2-year storm at outlet 3C of original topography for varying CN

<u>Geomorphic Landform Design:</u> The Geomorphic Landform Design (GLD) topography was designed using the GeoFluv program and included only the watershed affected by the valley fill (Figure 3c). The GLD watershed was digitally incorporated into the original topography using AutoCAD and then imported into WMS. Once imported into WMS the watershed was delineated using the same outlet point used in the original topography.

The watershed was modeled using curve number values of 84 and 67. The CN value of 84 was gathered from literature investigating the CNs of watersheds affected by MTRM (Bonta et al., 1997; Ritter and Gardner 1991; Taylor et al., 2009; Warner et al., 2010; Table 2), and the CN value of 67 was taken from the mine site permit file. The CN value of 67 will be used to represent the long-term hydrologic response of the reclaimed watershed five years after reclamation has occurred.

The delineated geomorphic landform design (GLD) watershed displayed in Figure 6 shows a similar overall watershed size and shape to the original topography with a total area of 524 acres, three acres larger than the original watershed. The watershed is composed of nine sub-basins that range in area from 7.8 to 170 acres with an average sub-basin area of 58 acres.

Table 8 lists basic sub-basin characteristics for the GLD watershed. The average basin slope of the GLD watershed, at 0.43, is 16% lower than the original topography. Basin lengths and MFDs for the GLD watershed are, on average, 9% and 6% larger than the original topography. Average MFS and MSL both decreased by 13% and 12% respectively with the average MSS increasing by 7% when compared to the original topography.

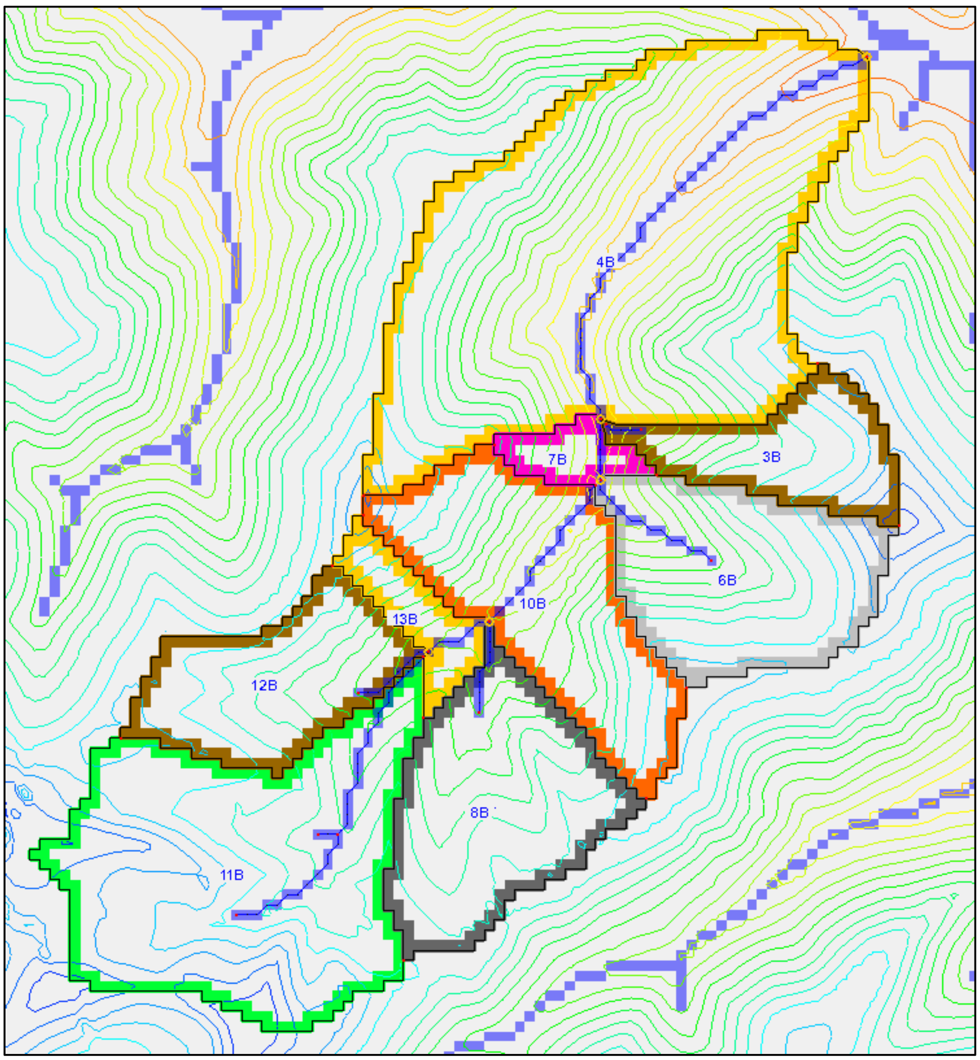

Figure 6: GLD topography delineated watershed and watershed sub-basins

Table 8: GLD topography basin data

	4B	3B	7B	6B	10B	13B	8B	11B	12B
Area (ac)	170	27.3	7.77	52.3	59.1	12.6	54.1	102	38.9
Basin Slope	0.51	0.42	0.59	0.45	0.48	0.43	0.32	0.31	0.34
L (ft)	4,700	2,210	754	2,163	2,270	1,180	2,450	3,420	2,240
MFD (ft)	5,350	2,390	938	2,584	3,040	1,380	2,680	4,300	2,400
MFS	0.16	0.35	0.51	0.30	0.20	0.37	0.16	0.14	0.19
MSS	0.05	0.35	0.03	0.22	0.07	0.12	0.15	0.14	0.15

Runoff results for the GLD at a CN of 84 indicate that the GLD watershed will experience larger peak discharge and total discharge volume than the original undisturbed watershed (Table 9). Precipitation values were entered into TR-55 in accordance with the values in Table 3.

Table 9: Hydrograph data for outlet of GLD topography for CN = 84

T (yr)	Q_p (cfs)	t_p (min)	V (ft^3 x 10^5)
1	521	732	18.2
2	686	732	23.4
5	1037	732	34.3
10	1369	732	44.5
25	1725	732	55.3
50	1904	732	60.8
100	2205	732	69.8
500	2855	732	89.4

The results of modeling the GLD topography at a CN value of 67 are displayed in Table 10. Peak discharge decreased by an average of 73% with the maximum difference occurring at the 1-year return period storm which saw an 89% decrease in flow rate. Total discharge volume decreased dropped by an average of 52% with the maximum difference occurring at the 1-year return period which saw a 71% decrease in total discharge volume. Figure 7 displays the storm response hydrographs of the GLD watershed at CN values of 84 and 67.

Table 10: Hydrograph data for outlet 3C of GLD topography for CN = 67

T (yr)	Q_p (cfs)	t_p (min)	V (ft^3 x 10^5)
1	56.7	750	5.20
2	105	744	8.02
5	238	744	14.7
10	372	744	21.6
25	542	738	29.4
50	634	738	33.5
100	795	738	40.5
500	1166	738	56.2

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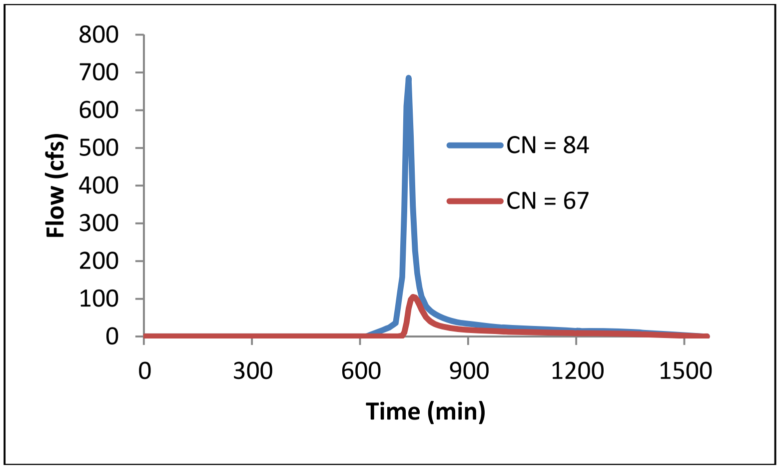

Figure 7. Storm response hydrograph for a 2-year storm at outlet 3C of GLD for varying CN

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2. Publications

Graduate student, Michael Snyder, will present preliminary results as an oral presentation at the Annual WV Academy of Science Meeting with a published abstract (abstract accepted):

Snyder, M., and L. Hopkinson. 2013. The hydrologic response of valley fills with alternative reclamation methods. 88th Annual West Virginia Academy of Science Meeting, April 6. Canaan Valley Institute: Davis, WV.

3. Information Transfer Program

A meeting was held between the research team and the website coordinator for the WV Water Research Institute (WVWRI). A plan was developed to establish how the project would be presented on the WVWRI website. A text description of the project, a fact sheet, and some of the models will be added to the website soon.

A press release was published by WVU Today on August 7, 2012. The article described the current progress of the project, as well as future research. The link to the article is http://wvutoday.wvu.edu/n/2012/08/07/wvu-water-research-institute-receives-grant-to-design-better-coal-mines.

A presentation of preliminary results will be given by Michael Snyder at the Annual WV Academy of Science meeting in Davis, WV in April 2013.

4. Student Support

Due to the short time between the start date and fall semester, we were only able to work with a MS student, Michael Snyder, in the fall semester. A PhD student funded by this project, Alison Sears, began in the spring semester. An additional MS student has been identified and will begin in the next reporting period (anticipated start date May/June, 2013)

5. Student Internship Program

NA

6. Notable Achievements and Awards.

The following achievements were completed in this reporting period:

- Two graduate students (one MS and one PhD) were assigned to the project and a MS student was identified for the project.
- Research progress on objective 1 and 2
    - Geomorphic valley fill design created with surface storage
    - Hydrologic response of GLD valley fills is under evaluation

Information Transfer Program Introduction

Three USGS 104b research projects and one USGS 104g research project are the subjects of this report. All are annual reports. In addition to publications, most projects had information transfer components. These include the following:

Identifying Geomorphic Design Parameters to Improve Flood Control and Waters Quality

Preliminary results were presented at the West Virginia Water Conference as a poster. The abstract was published in the conference program:

Buckley, C., L.C. Hopkinson, B. Mack, and J.D. Quaranta. 2012. Quantifying mature landform characteristics for geomorphic design in the coal-mining region of southern West Virginia. West Virginia Water Research Conference, October 30-31, 2012. Waterfront Place Hotel: Morgantown, WV. Poster.

Abstract submitted and accepted to present an oral presentation at the Environmental Considerations in Energy Production Symposium:

Buckley, C., L. Hopkinson, J. Quaranta, B. Mack, and P. Ziemkiewicz. 2013. Investigating design parameters in the design of West Virginia valley fills to support application of geomorphic landform design principles. In Environmental Considerations in Energy Production, April 14-18, 2013.

Stable Isotope Fingerprinting of Waters in an Area of Accelerating Marcellus Shale Gas Development

Sharma, S. 2012. Use of stable isotopes in shale gas research: examples from the Appalachian Region of eastern USA. International Workshop on Exploration and Exploitation of Shale Gas, National Geophysical Research Institute, Hyderabad, 19-20 December, Hyderabad, India.

Sharma, S., M. L. Mulder, A. Sack, T. Carr, K. Schroeder, R. Hammack, J. White, and D. Chambers. 2012. Isotopic fingerprinting of stray gas in area of accelerating shale gas development in the Appalachians. West Virginia Water Conference, October 30-31, 2012, Morgantown, WV.

Sharma, S., M. L. Mulder, A. Sack, L. Bowman, T. Carr, K. Schroeder, R. Hammack, J. White, and D. Chambers. 2012. Understanding natural variations of dissolved methane in areas of accelerating Marcellus Shale gas development. Geological Society of America National Annual Meeting, Nov. 4-7, 2012, Charlotte, NC.

Pelak, A.., S. Sharma, D. Chambers, and J. White. 2012. Spatial analysis of stable isotopic variations in surface waters of an area of accelerating Marcellus shale development in north-central West Virginia. Geological Society of America National Annual Meeting, November 4-7, 2012, Charlotte, NC.

Pelak, A., and S. Sharma. 2012. Comparison of stable isotopic variations in surface waters in five stages of Marcellus shale development in the Monongahela River basin of north-central West Virginia. West Virginia Water Research Conference, October 30, 2012. Morgantown, WV.

Modeling the Hydrologic Response in Surface Mining Watersheds with Redesigned Reclamation Practices

Graduate student, Michael Snyder, will present preliminary results as an oral presentation at the Annual West Virginia Academy of Science meeting with a published abstract (accepted):

Snyder, M., and L. Hopkinson. 2013. The hydrologic response of valley fills with alternative reclamation methods. 88th Annual West Virginia Academy of Science Meeting, April 6, 2013. Canaan Valley Institute, Davis, WV.

Press Releases Press releases were developed and released on several water resource research projects. Typically new awards, upcoming events, and interesting project highlights and results trigger the development of a press release. One example of a USGS-support project was a press release picked up by WVU Today on August 7, 2012. The article described the current progress of the project, Modeling the Hydrologic Response in Surface Mining Watersheds with Redesigned Reclamation Practices, as well as future research. The link to the article is: http://wvutoday.wvu.edu/n/2012/08/07/wvu-water-research-institute-receives-grant-to-design-better-coal-mines. Other examples include: WVWRI receives additional funding to expand water quality monitoring program; WVWRI expands monitoring project to Ohio and Allegheny River Basins with selection of three new partners; Scientists celebrate expansion of WVU-sponsored water quality monitoring program at Pittsburgh's Point State Park; and WVWRI introduces program to help fund regional water quality initiatives.

WVWRI Website A new design was developed for the Institute web site and went live in February, 2013. The site features WVWRI programs, projects, publications, events, contact information, news items, and other relevant information. Program and project information is updated on an on-going basis. Also, as programs and projects are completed, they are being archived on the site rather than being removed. Since the site launched, there have been 889 site visits and 673 unique visitors.

Some pages are more interactive and offer visitors up-to-date data. An example is the Three Rivers Quest (3RQ) page which serves as the prime dissemination tool for WVWRI's water quality monitoring and reporting project for the Upper Ohio River Basin. It features a ArcGIS Explorer online map to display water quality data collected by researchers and volunteer organizations. Since the site was launched in December 2012, there have been 1,633 site visits and 1,081 unique visitors.

State Water Conference A West Virginia Water Conference was held October 30-31, 2012 in Morgantown, West Virginia. The theme was Protecting Our Water Resources, providing for Our Energy Futures. Session Topics included: Protecting our Water; Planning Ahead Proactive Approaches; Monitoring Energy Production Impacts in the Upper Ohio River Basin; Water Quality Monitoring Programs; Geomorphic Consideration in Mining Reclamation; Gas Well Development; Stream Ecology/Restoration; Toxicity and Health. Twenty-eight abstracts were received; 183 attended; and there were 5 student posters.

A regional water conference is planned for September, 2014 in Shepherdstown, West Virginia. Virginia and West Virginia are spearheading the event. All other institutes within the mid-Atlantic region have been invited to participate.

Other Events Other outreach events included: Enhancing Public Understanding of Natural Gas Issues Conference June 6, 2012; May 22, 2013 Three Rivers Quest Project Launch/Commemorative Water Sampling Event December 2, 2012 (http://www.youtube.com/watch?feature=player_embedded&v=4KAVqh8qWAA) and Mini-Grant Check Presentation Event May 14, 2013 World Water Day Event March 22, 2013 (http://www.youtube.com/watch?feature=player_embedded&v=AVeGRkjYxhs)

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	2	0	0	0	2
Masters	3	1	0	0	4
Ph.D.	0	1	0	0	1
Post-Doc.	0	0	0	0	0
Total	5	2	0	0	7

Notable Awards and Achievements

Two MS theses supported with USGS 104b funding; 1 student graduated; the other to graduate summer 2013. Research papers in preparation for submission to journals; 1 in the final stage of acceptance. Project results presented at several regional/national/international conferences. Research highlighted in several university and regional magazines, articles, and news.